METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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Subscription Rates throughout the World - - 24/- per annum, Post free

Published monthly by THE KENNEDY PRESS, LIMITED.

REGISTERED OFFICE: 21, Albion Street, Manchester, 1.
Telephone: Central 0098. *Telegrams:* "Kenpred," Manchester.

LONDON OFFICE: Bedford Street, W.C. 2.
Telephone: Temple Bar 2629.

Company Meeting

HALE & HALE (TIPTON) LTD.

A Very Exacting Year — Excellent Results Achieved

MR. EDGAR HALE'S SPEECH

The eighth annual general meeting of Hale and Hale (Tipton) Ltd was held on December 29th, 1944, at the Station Hotel, Dudley, Mr. W. Edgar Hale, J.P., T.C., M.I.Mech.E. M.Inst.F. (chairman of the company), presiding.

The following is the Chairman's review of the Company's activities for the year ended 4th August, 1944, which was circulated with the report and accounts.

MANAGING DIRECTOR

During the year I considered that the time had arrived when I should be superseded as managing director and the choice of my successor unanimously fell upon Mr. Leppington, who has been in very close contact with me in the conducting of the business for a good many years I am delighted to say that he is filling this very important post with keenness and enthusiasm and at the same time, with every degree of helpfulness to everyone with whom he comes into contact. Mr Leppington has been in the service of the company for many years, and his fellow directors are delighted to see him installed in this very important office.

TRADING RESULT

Copies of accounts will be enclosed herewith and reference thereto will reveal that the trading profit, together with sundry other items as described, amounts to a little over £25,000 as compared with approximately £22,000 for last year, showing an improvement of roughly £3,000. From the profit figures have to be deducted sundry items, the principal one of which is £7,500, or thereabouts, for depreciation and obsolescence, leaving a net profit of approximately £17,000, showing an increase over the previous year of approximately £1,500. To this has to be added the balance brought in from last year approximating to £10,000, leaving a disposal balance of £27,000 odd.

The preference dividend has been paid on the usual dates at a cost of £2,750; then your directors decided that an interim dividend of 5 per cent. on the ordinary share capital should be paid also during the year, and they further proposed that a final dividend of 10 per cent. should also be paid. Your directors have decided upon this increase in dividend to compensate the proprietors for the conservative returns they have received out of the company's trading in past years. It will interest you to know that the liquid finances of this company have not been buttressed in any way by sharing in profit made by the subsidiaries. In this connection it is very interesting to observe the relationship between the amount of salaries and wages for the year as compared with the amounts of dividends for the year and, as heretofore, the dividends amount to roughly 1/50th of the wages and salaries. To illustrate the same point in another form, out of every £100 distributed in these channels, £98 is represented by salaries and wages, only £2 going to the ordinary shareholders.

Your directors also recommend that £2,500 shall be transferred to the reserve account for contingent obsolescence of buildings plant and machinery, and a further £5,000 to general reserve.

Giving effect to the above recommendations there remains to be carried forward approximately the same amount as last year.

BALANCE SHEET

It will be observed that the arrangement of the balance-sheet has been varied somewhat to conform to present-day practice, on the recommendation of your auditors, and the corresponding figures for the previous year are also shown, which is very helpful in the study of the balance-sheet.

It will be observed that the fixed assets have increased during the year by approximately £2,000 and the figure representing plant and machinery of £75,000 odd shows the original cost. Total depreciation has been written off to the extent of some £27,000.

The general reserve stands at the satisfactory figure of £30,000 in addition to which there is a further reserve of £15,000 specially earmarked on account of buildings, plant and machinery.

On the liabilities side it will be observed that there is a reduction of a little over £21,000 in sundry creditors, after provision has been made for the current and future liabilities, including taxation. It will be noted that at the date of the balance-sheet there was a bank overdraft of slightly over £5,000 which was purely incidental to variations as between debtors and creditors, prompted by the fact that your company always has liquidated its cash liabilities on the precise date that they fall due. To-day the company's bankers hold a substantial working cash balance and, finally, it will be observed that the surplus of floating assets over external liabilities amounts to £56,000 and shows an increase of some £4,000.

POST-WAR PROSPECTS

Your company has a very heavy order book indeed and is in the enviable position of having throughout the war period supplied the bulk of its tonnage and output to its old peace-time friends, and happily, too, the company will not be confronted with a difficult change-over period from war to peace, as the company's production really does not vary from one to the other.

Your technical staff is continually engaged upon the development of new uses and outlets, which are producing very good results indeed. We welcome the opportunity of analysing the problems of our users and potential users and we find our services are proving very acceptable in this connection.

SUBSIDIARY COMPANIES

Your directors feel equally optimistic in relation to the two subsidiary companies in respect of their peace-time prospects. The larger of the two, that is, Chatwins Limited, is an old-established business of repute, manufacturing, in the main, household grates and ranges under the trade name of "Sunbeam," "Sunbeamette," and "Eezikleen." all of which have excellent reputation amongst users and also amongst factors and wholesalers, through whom the company exclusively sells its products. In addition, it is intended to devote attention to a number of other branches directly concerned with house building which, collectively, should provide the company with a good many years of prosperous activity for all concerned. The smaller of the two, that is, J. and J. Whitehouse (Tipton) Limited, is again an old-established concern, producing what is known as the "Phœnix" brand of hollow-ware and similar products, mainly for export and for which there is every reason to anticipate a good, flourishing demand.

METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

JANUARY, 1945 VOL. XXXI. No. 183

"Combined Operations"

THE use of the expression "combined operations" in connection with the war has become so familiar to us that its application to trade and industry is not readily appreciated ; it was, therefore, particularly appropriate that Lord Woolton, Minister of Reconstruction, should use it in a recent address to business men. To call for combined operations to restore our trade and carry on the battle against unemployment is a topical way of calling for unity of action in peace as in war. The past five and a half years have shown what this country is capable of doing when there is unity of effort in a common cause, and it would seem possible—indeed desirable—that combined operations be applied to trade and industry as soon as hostilities cease. With this in view, some of the plans already prepared for post-war developments could be modified because there is a feeling that too many leaders of enterprise are still thinking of their individual competitive positions instead of gearing their respective capacities to the united effort of a whole industry.

Few now doubt that whatever may be the fruits of the present conflict when hostilities cease we shall face a new world, and unless our methods are elastic enough to embrace its new factors we shall fail to make our best contribution to the restoration of prosperity. The Government has prepared plans designed to solve Britain's social problems, but it must be remembered that the cost will be high and that it must be borne by industry ; their success in application, therefore, must depend upon industrial progress, and it will be necessary for the Government, employers and employees to unite in their efforts, not only to win through the transition stage from war to peace, but to prepare a lasting foundation for sustained prosperity. Many new problems of trade and industry will certainly be presented in the immediate future, through the flux of events, and to meet them Britain will need all her resources, not only of experience and experiment, but of outlook and vision ; will, in fact, need combined operations.

The announcement that vast export credits form part of the Government's plan to put Britain's trade on its feet when the war with Germany is over and before the Japanese have been defeated is an indication of the support to increase exports. Parliament is to be asked to raise the limit of the Government's liability under export guarantees from the pre-war figure of £75,000,000 to £200,000,000 ; to increase the sums available for the backing of the re-export trade ; and to abolish certain restrictive conditions which hampered the pre-war scheme.

To take full advantage of these export credits both trade and industry must be adequately organised, and the goods and manufactures must compare in ingenuity, quality and price with those of any other country. The intensity of industry's concentration on specialised war efforts has taught us much ; it has forced us to adopt greatly altered methods to ensure quality of product and increase the speed of production, and these methods must be adopted, where possible and profitable, to re-shape our various peace-time industrial practices. The application of many of these will bring about changes from pre-war practices which will greatly affect each section of industry. Combined operations will be needed to make these changes possible and to enable them to be used fully to win the battle of production.

The war years have shown how closely industrial progress is linked with research and here again the Government appreciates the need of fostering this aspect of industrial development. Indeed, all the post-war plans for industry indicate the need for intensified research activity. Elsewhere in this issue are presented the views of Mr. Devereux on the subject of industrial research and development in which he emphasises the need for applied research, so that industry may develop its manufacturing processes and products with the minimum of delay.

Despite the fact that trial and error methods continue to play a prominent part in what is regarded as technical and industrial progress, persistent research is gradually building up knowledge which is enabling us to progress at a more rapid rate. The results of fundamental research are appreciated more to-day than formerly, and the time lag in their application to industry is much reduced, but with a properly equipped development department staffed with the right type of men facilities would be available for further reduction of the gap to expedite advances.

In the metallurgical field Mr. Devereux refers especially to the application of the results of research in the determination of locked-up internal stresses, particularly in forged components, as a result of which designers can, with more confidence, use mechanical test figures of the material for design purposes. Mention is also made of improved fatigue testing methods which enables a designer to compare the fatigue properties of a new material with one of known performance under fatigue conditions. The results of further research indicate a relationship between the damping values and fatigue, and if the experiments in hand prove as fruitful as they are promising, it may soon be possible to establish the fatigue properties of a material more quickly than is now possible.

However much other aspects of progress may be considered in their application to Britain's prosperity, it is to advances in applied research that we must look for the forces that will really shape our future, but only by uniting our energies in a common endeavour to achieve success, in peace as in war, will prosperity be assured.

An Investigation of a Case of Season Cracking

By Thomas B. Crow, Ph.D., M.Sc., F.R.I.C.

(*Technical Director, Emery Brothers, Ltd., Birmingham*, 6.)

Fabricated by cold pressing and assembled in such a way as to set up an additional stress, some brass clips failed in service by season cracking and an investigation was carried out in an effort to determine the cause and methods of prevention. This report describes the investigation and gives the author's conclusions.

THE most commonly experienced instances of season-cracking occur in brass[1] articles which have been formed by cold work and which are in a state of internal stress. The *essential* conditions for the development of season cracks are, however, (*a*) a sufficiently high-tensile stress in the surface of the brass, and (*b*) a particular type of chemical attack upon the surface, although there is a common but incorrect impression that season-cracking can occur *only* when the stress present is internal. There is an equally common belief that low-temperature heat-treatment is a universally applicable preventive; the truth is, however, that it can be successfully used only when the stress responsible is internal. Since most cases are of this kind, it is easy to see how these impressions have become so well founded.

Liability to season crack can be detected in advance of service or storage by immersing the degreased and acid-cleaned article in a solution of mercurous nitrate[2] and leaving it therein for a few minutes. If cracks appear whilst immersed or within 24 hours of its removal from the solution, then it is safe to assume that the article would have season-cracked in service or storage.

In this article is described a case which recently came to the writer's notice, in which a brass article, fabricated by cold pressing to a certain shape, was assembled in such a manner as caused a definite alteration of that shape and a consequent setting up of an additional (elastic) stress, which would remain in existence so long as the article was in service. Failure by season cracking had taken place in several "sets" which had gone into service.

The article under notice was a simple circular clip (Fig. 1) made from "half-hard" brass strip of 63/37 composition which, on leaving the press shop, had a somewhat open shape as Fig. 2. This clip was not given any "season crack anneal," but, after nickel-plating, was fitted by means of a tiny bolt and nut to the end of a shouldered porcelain tube of $\frac{3}{8}$ in. diameter, the nut being tightened until the clip had a firm grip upon the tube. The bolt and nut also served as an anchorage for the end of a wire which carried a current. Fig. 4 shows the clip in the closed (assembled) condition, from which it will be seen that appreciable deformation of the clip was inevitable. This deformation would cause the setting up of external elastic stresses which, as already remarked, are permanent whilst the assembly is in service. If the nut were at any time slackened off, the clip would revert to the open form of Fig. 2 (provided that no erstwhile change in the physical properties of the clip had occurred) and the elastic stress would disappear. Fig. 3 shows a half-closed clip to which reference will be made later. It should be noted that Figs. 2, 3 and 4 faithfully show the relative changes in shape of the clip in passing from the open to the half and fully closed conditions respectively.

In carrying out investigations of the cause and prevention of failure by season cracking of a particular article in service under particular conditions, two

FIG. 1

FIG. 2

FIG. 3

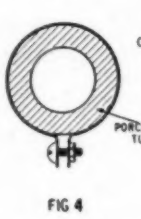


FIG. 4

FIG. 5.

FIG. 6.

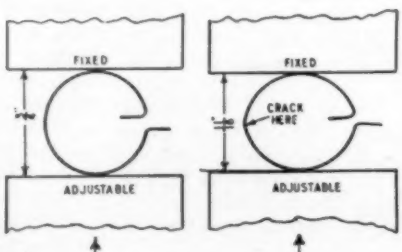
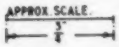


FIG. 8.A. FIG. 8.B.

FIG. 7.



1 Cold-rolled brass sheet or strip, 63 to 70% copper.

2 No very definite concentrations of solution are necessary. The following solution was used in tests carried out in this account:—

To 100 cc. conc. nitric acid add 100 gms. mercurous nitrate crystals and make up to 1,000cc. with distilled water. Dilute sufficient quantity of this solution 20 times for each batch of three (or less) small articles.

agencies are available in the laboratory, as already mentioned—namely, the mercurous nitrate test and the "season crack low-temperature heat-treatment." The first of these enables an investigator to predict in a few hours whether an article would season crack during prolonged future service, and the second enables him to prescribe a definite preventive treatment for risky cases where it is particularly important that season crack failure shall not occur in service.

It will be the purpose of this article to show, however, by describing systematically conducted series of laboratory experiments in which the two above agencies were fully used, that their misplaced application may lead to confusing and disappointing results ; such misapplication arising from a lack of a full knowledge or appreciation of what is happening at every progressive stage of manufacture, assembly and service. It is hoped that this account may be the means of avoidance of such pitfalls, and suggest the kind of way in which similar cases of season cracking failure may be tackled. In a later portion of this account, the possibility of employment of alternative materials of manufacture, which are known to be free from season cracking propensities, is considered.

In order to dispose of any suggestion that the temper[3] of the "half-hard" brass strip supplied for making these clips might be responsible for the season cracking (notwithstanding the fact that from a manufacturing point of view it was quite satisfactory) a quantity of strip (63/37) of three different tempers[4] was rolled to the required widths[5] and gauges,[6] and a sufficient number of clips for experimental requirements was made up from metal of each temper in each width. In all, seven series of experiments were made, and each series was simultaneously performed on three parallel lines employing respectively clips made from the three different tempers and repeating each test in triplicate. Altogether, 129 (3×43) clips were tried out, and in no instance was there the slightest evidence to suggest that there was any connection whatever between their temper and their season cracking propensities. Further, variation in the width was of no consequence whatever.

The seven series of experiments will now be described. It should be noted that identical treatment, so far as time of immersion in the mercurous nitrate solution, time and temperatures of heat-treatment, strength of solutions, etc., was given to all test clips in any series. Degreasing and preliminary pickling were uniformly adopted throughout.

1st Series.—Twenty-seven clips (9 of each temper, made up of 3 clips of each width) were closed up by pressure of the thumb and finger on the sides until they assumed the shape of Fig. 4 and were secured thus by fine nickel wire passed through the holes and twisted up. They were then submitted to a 5 min. immersion in the mercurous nitrate solution (i.e., whilst under stress). All failed whilst in the solution or very shortly afterwards. In all cases a large crack developed across the width of the clip at a point on its periphery diametrically opposite the ears. (See Fig. 5.)

2nd Series.—This was repeat of the 1st series, except that the clips were closed up on to short lengths of glass tube and gripped up by wiring instead of by the small bolts which were used by the manufacturer in assembling. The diameter of the glass tube was the same as that of the manufacturer's porcelain tube. By this means the stresses set up by the manufacturer in assembling were reproduced for the purposes of the season crack test. Again, all failed very quickly, this time as shown in Fig. 6, and of course the clips lost their grip on the glass tube.

3rd and 4th Series.—Thirty-six open clips (Fig. 2) were given a five hours' heat-treatment at 250°–260° C. in an electrically heated air oven. This treatment does not in any way cause even partial annealing, and the clips, on completion of the heat-treatment, retained their springiness.

For the 3rd series, 18 clips (2 of each width in each temper) were season crack tested exactly as they left the heat-treatment oven (i.e., open shape). No failures occurred. (Note especially here that the normal procedure of an inspector would probably be to say that the clips, having been season crack annealed and having subsequently passed the season crack test, would be fit for service.) For the 4th series the other 18 clips which had been heat-treated were gripped up on to glass tubing, as described for the 2nd series, and season crack tested. All failed within a few minutes, on the corners as at Fig. 6, notwithstanding the heat-treatment. As a direct result of this series, a further experiment was performed upon clips of the 3rd series after they had remained intact and undisturbed for 24 hours, and whilst they were still wet with the deposited mercury—namely, a few of them at random were gently closed by finger pressure upon glass tubes and held thus by the ears for less than a minute. They failed, again at the corners, as Fig. 6.

5th and 6th Series.—Thirty-six open clips, as received, were gripped up with fine nickel wire on to short lengths of glass tube and heat-treated (as before) in this condition. By this means, be it noted, the clips were being heat-treated whilst under the elastic stresses caused by closing up. For the 5th series, 18 clips (properly selected as to width and temper, as before) were season crack tested directly after emergence from the heat-treatment —i.e., closed up on the glass tubing. No failures occurred. For the 6th series the other 18 clips were released from the glass tube by nipping the binding wire. They partially sprung back to a shape intermediate between fully closed and fully open (see Fig. 3). They were then tested in mercurous nitrate and all remained intact. The results of these two series led to two further experiments, one on each series. After 24 hours clips of the 5th series were released, and clips of the 6th series gripped up on to glass tubing, in each case whilst they were still wet with mercury, and allowed to remain undisturbed for 24 hours. No failures occurred.

7th Series.—A critical survey of the results of the first six series of experiments appears to indicate reasonably conclusively that :—

(1) Temper of the rolled strip is not a factor in the causes of season cracking.

(2) That ordinary season cracking anneal of the fabricated but unassembled clip is not necessary, and is in fact ineffective for this particular job.

(3) The real cause of the trouble is the elastic stress (and corresponding deformation) set up in assembling the clips on to the porcelain. If this could be abolished, or reduced to a very small amount, then the trouble would cease.

4 By "temper" is meant the physical properties directly attributable to cold-rolling. Vickers' Hardness Numbers roughly indicate temper. See Note 5.
5 Quarter-Hard, V.P.N. = 113 ; Half-Hard, V.P.N. = 136 ; Hard, V.P.N. = 156.
6 $\frac{1}{2}$ in., $\frac{3}{8}$ in., $\frac{1}{4}$ in.
7 26 S.W.G. = 0·018 in.

It could be abolished in one of three ways, namely :—

(*a*) By relieving it after final assembly on to the porcelain, by heat-treatment corresponding to Series 5.

(*b*) By relieving it before final assembly, but under the same conditions as will obtain when it is finally assembled.[7]

(*c*) By not allowing it to arise.

With regard to (*c*), if the clips could be manufactured of the correct curvature to fit snugly on to the tube without more than a barely noticeable deformation, then we should probably be out of the wood. It was not possible to do this in the laboratory, but a clip of the correct curvature with one ear inwards and one outwards was produced (see Fig. 7). For test purposes, this can be regarded as a closed-up clip which can be assembled without deformation. Accordingly, 12 such clips were made up (3 in each temper) and, without any heat-treatment, were put at once through the mercurous nitrate test. After 24 hours all were intact. Whilst still wet, the 12 clips were compressed slightly between two heavy blocks of metal (Fig. 8A) and allowed to remain thus for several hours. All remained intact. The two blocks were then moved closer together, so as to increase the deformation by about $\frac{1}{16}$ in. (Fig. 8B). All failed. This series does not reproduce the stress conditions which would be set up if a clip of the correct curvature were made, assembled and tested on glass tube and therefore its inclusion in this report may be considered by some to be of questionable value. It did indicate however at the time, a possible alternative solution to the heat-treatment methods 3 (*a*) or (*b*), which would be accompanied by certain workshop difficulties and cause delay in production, and, were it not for other alternatives (Series 8, 9, 10) it might have demanded further attention.

There does not appear to be any particular virtue in using brass for this job. Perhaps convention and certain other advantages automatically decide one in its favour, but there are certain other metals which are believed to be substantially free from this evil[8] which are worth consideration. Among such are copper and a 90/10 copper-zinc alloy, known as gilding metal.[9] If one may digress for one moment, it is not out of place to mention here that in the writer's opinion makers of stamped brassfoundry, chandelier chain, picture hanging chain and the like might do well to consider the claims of gilding metal as an alternative to brass, from the season cracking point of view. Accordingly, a quantity of strip in hard[10] and half-hard[11] tempers in copper and in gilding metal was rolled to a gauge of 0·018 in. and in three widths as before. The $\frac{9}{16}$ in. wide strip only was used throughout the experiments now to be described.

8th Series.—Three clips of each metal in each temper (12 in all) were submitted to the mercurous nitrate test in the open (as made) condition. No failures occurred after 14 days.

9th Series.—Twelve clips, as for Series 8, were wired up in the same manner as Series 2, and submitted to test in mercurous nitrate solution. No failures occurred after 24 hours. After this time the clips were released and resumed their original shape. After 14 days they were still intact and fully springy as tested repeatedly by closing the ears together.

10th Series.—Twelve clips, as for Series 8, were wired and gripped up on to glass tubing as Fig. 4. These were tested in the solution and all were intact after 24 hours. The wiring was then nipped off ; clips sprang open and were in every way satisfactory, as described for Series 9, after 14 days.

The conclusion is therefore reached that either copper or gilding metal is particularly suitable for this job ; preference should be given to gilding metal, owing to its greater strength. Again, within the limits tried, temper is without effect. It should be noted that Series 10 approximates to service conditions and no heat-treatment was given or necessary.

General Conclusions

The general conclusions to be drawn from the work recorded in this report may now be stated :—

(1) The virtues of copper and 90/10 gilding metal over 63/37 or 70/30 brass should not be lost sight of in cases where trouble has been experienced or must be prevented at all costs.

(2) Season crack heat-treatment of brass articles must be carried out when those articles are in the same condition of stress as they will be in in service.

(3) Mercurous nitrate tests must likewise be carried out upon the article whilst it is in the same condition of stress as it will be in when put into service.

(4) It is abortive and misleading and definitely wrong to " certify " articles which have passed the mercurous nitrate test after fabrication as fit for service until the service conditions of such articles have been studied sufficiently.

Acknowledgment is hereby made to the directors of Emery Brothers, Ltd., for their kind permission to publish this investigation, and to Mr. G. G. Woods for his assistance in the experimental work.

8. That is, after pressing, temporarily assemble on to iron bars of $\frac{3}{8}$ in. diam. and heat-treat. Release, nickel-plate, etc., and finally assemble. This corresponds to Series 6, both parts.

9 That is, liability to season crack.

10 There are several compositions of gilding metal, but in this report 90/10 is considered.

11 Hard copper, V.P.N. = 110 ; hard gilding metal, V.P.N. = 134.

12 Half-hard copper, V.P.N. = 102 ; half-hard gilding metal, V.P.N. = 113.

Improved Lead-Bearing Alloys

THE lead-base bearing metals containing small additions of alkalines and earth-alkalines (" Bahn-Metall " or Bn-metal) possess excellent bearing properties, and contain no strategic metals. Their disadvantages are loss of hardening agents on remelting, and hardness changes when exposed to higher temperatures for longer periods of time. The object of a research by Schmidt* was to overcome the latter two difficulties.

The solubility of sodium in lead was redetermined, and it was found that the sodium content in Bn-metal exceeds the maximum solubility at room temperatures to an extent considerably larger than previously assumed. Hardness tests proved sodium to be the principal hardening element, followed by lithium. Sodium and lithium are reduced by two-thirds and one-half, respectively. Additions of barium were found to be advantageous, and lithium may be fully replaced by magnesium.

Analyses recommended are : 0·7 Ca, 0·4 Ba 0·2 Na, 0·02% Li and approximately 0·02% Al ; 0·7 Ca, 0·4 Ba, 0·2 Na, 0·004% Mg and approximately 0·02% Al, balance Pb. It is claimed that these new alloys show no loss of strength in temperature ranges heretofore reserved for babbits.

*Erich Schmidt. *Z. Metallkude*, **35** 1943, pp. 85-92.

The Identification of the Constituents of Welding Electrode Coatings

By R. C. Vickery, Ph.D., M.Sc.

The chemical analysis of arc-welding electrodes gives little or no indication of the individual constituents of the coating composition. This paper represents an attempt to formulate a scheme whereby the specific identity of welding electrode coating constituents may be ascertained with greater accuracy than that afforded by the most carefully rationalised chemical analysis.

OWING to the lack of published information correlating welding rod coating compositions with the properties of electrodes, it is necessary, when attempting comprehensive research on the subject, to examine the coatings of existing manufactured welding electrodes.

Purely in the interests of science and apart from the commercial aspect, the secrecy with which manufacturers surround their coating formulæ is to be deprecated ; and the information given in patent specifications is but rarely with scientific basis, claims of specific attributes of electrodes being usually conspicuous by their absence.

Chemical analysis of welding rod coatings is insufficient for the identification of their components as usually radicals only are estimated, and accurate rationalisation of the analytical results is almost an impossibility. Mineralogical examination of the coating constituents must, therefore, be resorted to, and this combined with the results of a chemical analysis can give information of extreme interest.

To facilitate examination of electrode coatings, the author has compiled a scheme utilising the mineralogical and chemical attributes of the most common components ; this, if applied with the usual precautions and care, gives results approximating fairly closely to the truth. The method as here described can only be applied to the ferrous type of welding rod, as the components of non-ferrous electrodes are of such reactivity, both with themselves and with the reagents employed in the methods of separation as to preclude any all-embracing scheme. The author has found, moreover, that in the majority of cases, the coating compositions of non-ferrous electrodes are relatively simple as compared with their ferrous counterparts, a careful rationalisation of the composition as given by chemical analysis being all that is required.

Materials to be Identified

In the coatings of ferrous electrodes the constituents most commonly found are, apart from binding agents, i.e., Na and K silicates :—

Rutile	Asbestos	Powdered metals
Ilmenite	Magnetite	Mica
Quartz	Hæmatite	Witherite
Felspars	Pyrolusite	Enstatite
Kaolin	Hausmannite	Cryolite
Calcite	Siderite	Graphite
Dolomite	Iron powder	Magnesite
Fluorspar	Ferro-alloys	Alumina
Talc		Organic matter

To these might be added several materials which are claimed in patent specifications, but which are isolated instances of little importance, e.g., powdered glass, carborundum, braunite, rhodocrosite, etc.

The essential properties of the more common of these compounds may be tabulated :—

TABLE I.

Substance.	*Magnetic Props.	Density.	† μ
Wood flour	—	1·5–1·6	—
Bentonite	—	2·00	1·52 (av.)
Graphite	—	2·16	—
Asbestos	—	2·25	—
Gypsum	—	2·32	1·68, 1·5
Brucite	—	2·39	1·56, 1·58
Bauxite	—	2·55	1·57
Felspars	—	2·55 (av.)	1·52, 1·53, 1·53
Kaolin	—	2·62	1·56
Quartz	—	2·66	1·55, 1·54
Calcite	—	2·71	1·69, 1·49
Talc	—	2·75	1·54, 1·59, 1·59
Sodium fluoride	—	2·79	1·34
Dolomite	—	2·85	1·68, 1·5
Wollastonite	—	2·86	1·62, 1·63, 1·63
Cryolite	—	2·98	1·34
Biotite	—	2·98 (av.)	1·5, 1·6, 1·6
Magnesite	—	2·99	1·7, 1·51
Carborundum	—	3·17	2·65, 2·7
Fluorspar	—	3·19	1·43
Enstatite	—	3·20	1·67
Lime	—	3·40	1·84
Magnesia	—	3·70	1·74
Alumina	—	3·70	1·77
Ferro-silicon‡	—	3·80	—
Siderite	—	3·86	1·87, 1·63
Rutile	—	4·22	2·9, 2·6, 2·8
Witherite	—	4·32	1·5, 1·7, 1·7
Pyrolusite	+	4·75	—
Hausmannite	+	4·86	2·46
Ilmenite	+	4·90	—
Magnetite	M	5·05	—
Hæmatite	+	5·10	3·22, 2·94
Ferro-titanium‡	—	5·69	—
Ferro-vanadium‡	+	6·66	—
Chromium powder	—	6·92	—
Ferro-chromium‡	*m*	7·13	—
Ferro-manganese‡	—	7·49	—
Iron powder	M	7·86	—
Nickel powder	—	8·9	—
Ferro-molybdenum‡	*m*	9·5	—
Tungsten powder	—	19·3	—

* M = highly magnetic; *m* = moderately magnetic; + = weakly magnetic; — = non-magnetic.

† The figures given are for η; ω, ϵ; or α, β, γ respectively.

‡ The figures for the ferro-alloys are for those containing 60% Si, 65% Ti, 60% V, 75% Cr, 85% Mn, and 70% Mo respectively.

Scheme of Separation

It will be seen from Table I that it is possible to segregate the substances mentioned, by differences in magnetic susceptibility, into three groups, each of which is further subdivided by density determinations, whilst the final observation of refractive index or of chemical reactions will usually be sufficient to enable the individual constituents to be identified. The following scheme may be employed.

1. *Initial Treatment.*—After being detached piecemeal from the core-wire, the coatings of three electrodes from a batch (four if they are only 14 in. in length) are boiled for twenty minutes with 200 ml. of distilled water in order to dissolve the sodium and potassium silicates usually employed as binding agents. The solution obtained should be examined chemically, or otherwise, for radicals other than K_2O, Na_2O and SiO_2, which would indicate the existence in the coating of water-soluble materials other than water-glass—probably

inorganic salts, but it should not be omitted to test for such binding agents as dextrine, starch, etc.

After this boiling, it may usually be assumed that the binding silicates have been dissolved and the grains of the coating constituents freed. The suspension is filtered hot through a Whatman No. 2 paper, and washed thrice with boiling water, the filtrates being subjected as indicated supra to tests for radicals other than those of Na and K silicates—in actual practice this is confined initially to tests for anions other than Si^{----}.

The filter carrying the disintegrated coating is dried in a hot air oven at 105–110° C.; higher temperatures than these are inadvisable owing to the possible decomposition of carbonates or organic matter.

One point which might be noticed during this preliminary treatment, is the odour present whilst the suspension is being boiled, as it has been observed[1] that interaction occurs between ferromanganese and sodium-silicate solution resulting in the formation of nascent hydrogen and acetylene with several other volatile, odiferous hydrocarbons. If, therefore, such an odour be noticed it may be safely concluded that ferro-alloys are present.

When dry and removed carefully from the filter (taking care not to injure the paper) the finely divided mixture is passed through a 100-mesh sieve. It is possible that a certain amount of material will be retained by the gauze at first, but unless this residue shews evidence of being particularly different from the bulk of the coating it is crushed in an agate mortar until all is passed through the sieve. There are relatively few materials employed in electrodes to-day which are much larger than 90–100-mesh, and when a large amount of material is retained by a sieve of the former size it is usually homogeneous and may easily be identified, e.g., tungsten carbide.

Whilst on the subject of grain-size of electrode coating constituents, it might be mentioned that as far as the identification of the components is concerned, sieve-analysis is of little value as the grain-size of powdered minerals varies so greatly, some manufacturers employing calcium carbonate as a rather coarse marble powder, whilst others use air-floated chalk.

2. *Preliminary examination.*—As a preliminary to actual separation, it is usually advisable to examine the powdered coating microscopically under direct lighting; the author employs a binocular microscope magnifying 60X, but quite good observations may be made with magnifications as low as 25 diameters. This micro-examination is essentially for the identification of organic materials and asbestos, but will also give to an experienced worker a useful indication of what substances may be anticipated in the separations (infra).

The organic material met with at this stage is in early every case a form of cellulose, usually wood flour of some description. Figs. 1–5 illustrate the microscopical appearances of some of the different types of cellulose encountered as well as the microscopical appearances of asbestos powder.

3. *Magnetic separation.*—The microscopical identification of minerals by direct vision only, without the aid of polarised light, is a procedure in which one can only attain efficiency by practice, and a well-experienced worker can occasionally dispense with any further examination. With the recent advances in the manufacture of welding electrodes, however, the complexity of the coating compositions renders direct visual identification a matter of increasing difficulty, especially where varying amounts of different ferro-alloys are used.

After the preliminary microscopical examination, therefore, the mixture is extracted with a bar magnet over paper; this will remove iron powder, magnetite,

Fig. 1.—Wood flour x 60. Fig. 2.—Cotton fibres x 30.

Fig. 5.—Asbestos powder x 60.

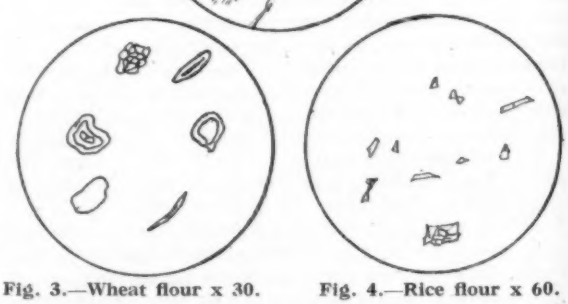


Fig. 3.—Wheat flour x 30. Fig. 4.—Rice flour x 60.

and a little of the ferromolybdenum and ferrochrome. Electromagnet separation is then carried out on the residue in the usual petrological manner. The electromagnet employed by the author is similar to that described by Holmes.[2] The essentials of its construction are, a core of soft iron some 10 in. long, bent U-shaped with a curve of 1 in. internal diameter to give arms about 4 in. long which are bound in opposite directions with seven layers of 40 turns each of 16 S.W.G. wire. The two movable poles piece are $1\frac{1}{4}$ in. wide and $\frac{1}{4}$ in. thick. Using as the source of current an 8-volt cell the moderately magnetic substances are attracted by poles $\frac{1}{2}$ in. apart and feebly magnetic materials by poles $\frac{1}{4}$ in. apart. The orthodox technique of its use is, however, considered somewhat tedious in that the current has to be switched off to enable the grains adhering to the poles to be removed—this usually necessitating the use of a camel's-hair brush. To obviate such a prolongation of the operation the author inverts the magnet and places a tray of Kraft paper over the poles as shewn in Fig. 6. The sides of the tray are reinforced with thin card and the corners of one of the long ends left unsecured so as to form a hinged side which will turn down and facilitate removal of the contents of the tray. The inner surface of the tray is marked with two lines as illustrated

1 Bliss. "Footeprints," 7, June, 1934.

2 "Petrographical Methods and Calculations," London, 1921.

thus producing three visual divisions which are marked consecutively A(*m*); B(+); and C(−). The material under examination is placed in the portion of the tray marked C(−) and the magnet activated by an electric current. After passing the mineral mixture over the poles of the magnet by moving the container backwards and forwards etc. the tray is moved in a sideways direction so that compartment A is above the poles. The more highly susceptible materials having been attracted to the magnet in compartment C remain above the poles whilst the tray is moved, and are deposited in section A when the tray is lifted from the magnetic field; the process is repeated until no further grains follow the magnet into the compartment A; a strip of card is then placed along the line separating the sections A and B. The process is repeated employing a shorter distance between the poles the particles then attracted being deposited in compartment B. Thus we have the original mixture divided into four portions corresponding to the magnetic susceptibilities of its ingredients.

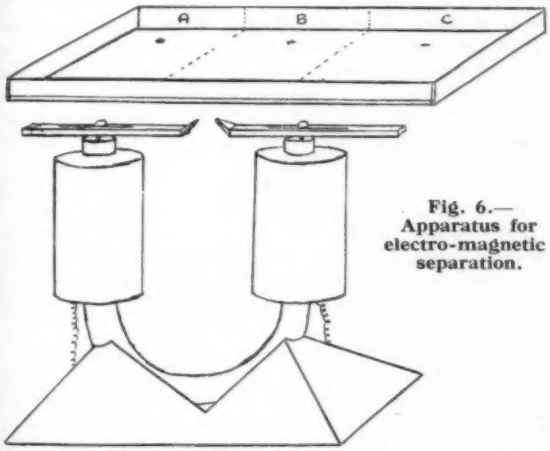


Fig. 6.—Apparatus for electro-magnetic separation.

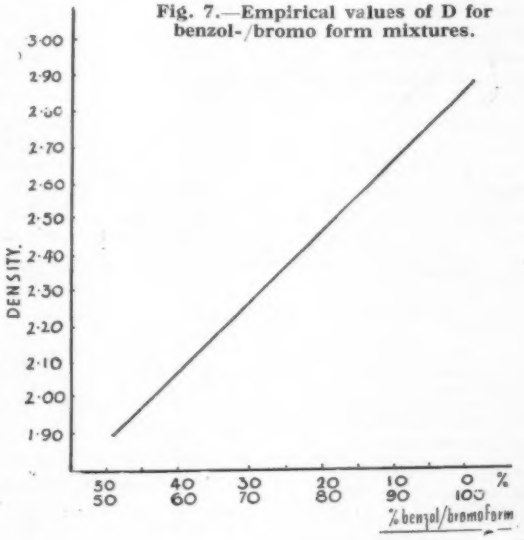
It is possible, in separation of the constituents of a commercial electrode coating, that one, or more, of these sections will be represented by an apparently homogeneous powder; if this homogeneity is confirmed by microscopical examination, no further separations need be carried out upon that portion of the material which may then be identified by the confirmatory tests indicated in Section 5.

Where the material in each compartment is heterogeneous, however, it must be subjected to separation by suspension in liquids of varying densities, as described in the following section. One further point must be borne in mind, i.e., the possibility of impurities in substances rendering them more amenable to magnetic separation than would be the pure material, for example, the inclusion in asbestos fibres of small amounts of magnetite, etc., would lead to the occurrence of asbestos in compartment A or B as well as C; further, in the case of carborundum, the methods of its manufacture are such as to include quite a fair amount of iron in the finished product, which might lead to the finding of this material also in a theoretically incorrect division.

4. *Density separations.*—For this process it is necessary to employ liquids of varying specific gravity. Up to densities of 2·9 bromoform/benzol mixtures may be employed, the empirical values of D for some of these mixtures being shewn in Fig. 7. From 2·8 to 3·3 admixtures of methylene iodide with benzol are used, the nominal densities attained being illustrated in Fig. 8.

It will be seen from Table I that these liquids are applicable only to the non-magnetic materials and that one-third of these have densities higher than 3·3. In view of this fact the author reverses the usual separation procedure in that he employs methylene iodide mixtures before those of bromoform. The operation of separation by these liquids is well-known and needs no repetition,

Fig. 7.—Empirical values of D for benzol-/bromo form mixtures.



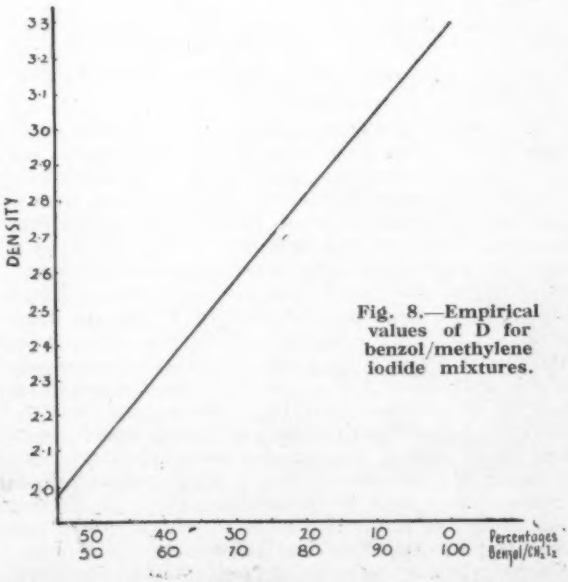


Fig. 8.—Empirical values of D for benzol/methylene iodide mixtures.

for those who are not familiar with the technique, however, reference may be made to the works of Holmes,[2] Milner,[3] and Raeburn.[4]

The "sink" and "float" process having been carried out with methylene iodide mixtures, the heavy minerals are separated via a tap funnel, filtered off, and washed

in the usual way with benzol. Further separation of the heavier material may then be carried out by the use of thallium mercurous nitrate[2, 3, 4] which in the fused state has a density of 5·3. Of the materials heavier than this, tungsten powder may be separated by the use of mercury. After removal by filtration of the solids suspended in the separating media, the filters and their contents are dried on a sand bath. The benzol, bromoform and methylene iodide employed are subsequently recovered by distillation, and employed for further separations.

By use of solutions of the compositions indicated in Table II, we are enabled to subdivide the non-magnetic substances into eight sections, so that by the employment of magnetic and density separations we have eleven groups of the coating materials (Table III).

TABLE II.

Components.				Density.
	%		%	
Bromoform	77	Benzol	23	2·45
"	91	"	9	2·69
Methylene iodide	84	"	16	2·90
" "	92·5	"	7·5	3·10
Methylene iodide				3·30
Thallium mercurous nitrate				5·30
Mercury				13·55

TABLE III.

Group 1.—Highly magnetic: Magnetite, iron powder.	*Group* 7.—Non-magnetic—D > 2·90, < 3·10: Cryolite, biotite, magnesite.
Group 2.—Moderately magnetic: Ferro-molybdenum, ferro-chromium.	*Group* 8.—Non-magnetic—D > 3·10, < 3·30: Carborundum, fluorspar, enstatite.
Group 3.—Weakly magnetic: Ilmenite, ferrovanadium, hæmatite, hausmannite, pyrolusite.	*Group* 9.—Non-magnetic—D > 3·30, < 5·3: Lime, magnesia, alumina, ferro-silicon, siderite, rutile, witherite.
Group 4.—Non-magnetic—D < 2·45: Wood flour, bentonite, graphite, asbestos, gypsum, brucite.	*Group* 10.—Non-magnetic—D > 5·3, < 13·5: Ferro-titanium, chromium, ferro-manganese, nickel.
Group 5.—Non-magnetic—D > 2·45, < 2·69: Bauxite, felspars, kaolin, quarts.	*Group* 11.—Non-magnetic—D > 13·5: Tungsten powder.
Group 6.—Non-magnetic—D > 2·69, < 2·90: Calcite, talc, sodium fluoride, dolomite, wollastonite.	

5. *Ultimate identification.*—Group 1. The two members of this group may be separated with ease by the use of fused thallium mercurous nitrate. By fusion of a mixture of the three substances, magnetite, iron powder and the thallium salt, it will be found on cooling that it is possible to cut the melt in two, thus attaining a complete separation. The salt being soluble in water, the powders may thus be obtained in the disintegrated state. Apart from the detection of Fe by the thiocyanate reaction, the density separation is sufficient for the identification of this group, although the possibility of contamination of the iron powder by ferromolybdenum and/or ferrochrome must be borne in mind and the heavier fraction from the melt separately tested for Cr and Mo as given in the following section.

Group 2. Although there is a fairly wide difference between the densities of the two ferro-alloys constituting this group, we are unable to take advantage of it and must therefore rely upon chemical tests only. Differentiation may be made between the two alloys by identification of chromium and/or molybdenum by the use of the benzidine and *a*-benzoin-oxine tests respectively.[5]

Group 3. The main difficulty in this section lies in the differentiation between hausmannite and pyrolusite. Detection of manganese in the group by the bismuthate method will not specifically indicate the presence of either of them, and as their densities are relatively close, one must rely upon visual identification under the microscope; this is comparatively simple, for under direct lighting hausmannite appears of a brownish-black colour, whilst that of pyrolusite is bluish-black, rather reminiscent of tempered steel. The presence of ilmenite may be confirmed or otherwise by the reaction obtained with tannic acid in oxalate solution[6] or with acidified H_2O_2. Ferro-vanadium is not so easily identified, but the acid-peroxide test for Ti may be adapted for this purpose, as the red colour produced in that reagent by Ti is removed by the addition of HF, whereas that obtained by V is not. In view of the presence of other iron compounds, the existence of hæmatite in this group is made known by its conversion to the highly magnetic Fe_3O_4 on heating. After subjecting the mixture on charcoal to red heat for a few minutes, any magnetite formed by reduction of the hæmatite may be readily extracted by the use of a bar magnet.

Group 4. Asbestos and wood pulp, if present, will already have been identified microscopically in the second stage of this examination. The observation of a red colouration imparted to a flame test is indicative of the presence of gypsum, this being confirmed if barium chloride reveals the existence also of sulphate. Similarly the detection in the mixture of magnesium by quinalizarin[5] is considered to indicate brucite. Bentonite being of an amorphous nature will readily adsorb aqueous malachite green solution and the colour remains after washing, whilst with the other materials present it is removed by warm water. This process may be observed microscopically whilst at the same time the colour of the graphite is its own confirmation, no further tests being required.

Group 5. This group may be subdivided by the employment of a liquid of D:2·60, but this is hardly worth while, as the members must ultimately be differentiated microscopically. As Al_2O_3 and SiO_2 are the predominating radicals in this group, chemical identification cannot be undertaken, and the only means of differentiating between the individuals is that of determining their indices of refraction. Accordingly, a small representative portion of the mixture is examined microscopically dry, but under a cover-slip; when the grains have been focused, cinnamon oil (μ1·53) is permitted to seep between the slide and the cover-slip by capillarity; the apparent disappearance of any of the grains will indicate felspars. When this observation has been made a piece of filter paper is applied to one edge of the cover-slip whilst a drop of brom-toluene (μ1·55) is placed at the opposite edge, thus by absorption of the cinnamon oil by the paper, the brom-toluene is drawn under the cover-slip to replace it. It is necessary to employ one drop of the second reagent for complete removal of the previous liquid, and another drop for observation. If any grains seem to disappear in brom-toluene they are taken to be quartz. This proceedure is repeated with mono-bromo-benzol (μ1·56) for kaolin and ortho-toluidine (μ1·57) for bauxite. It must be remembered, however, that the indices of refraction given for the minerals are averages, so that the question of the proportion of mineral grains affected by each liquid must be

3 "Sedimentary Petrography," 3rd Ed., London, 1940.
4 "Alluvial Prospecting," London, 1927.

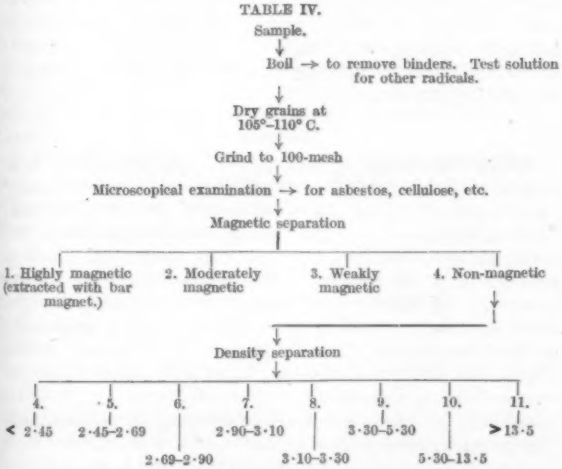
5 B.D.H. Book of Organic Reagents for "Spot Tests," 8th Ed., 1941
6 Schoeller and Powell. Analysis of Minerals and Ores of the Rarer Elements." London, 1919.

taken into account when stating whether or not a mineral is present.

Group 6. The mixture is first extracted with cold 50% acetic acid, and then with hot acid of the same concentration, the two extracts being collected separately. The cold extract is examined for Ca by the flame test and the hot extract for Mg with quinalizarin or "magneson."[5] Positive results indicate respectively calcite and dolomite. Owing, however, to the association in occurrence of the two minerals it is necessary once more to take into account the approximate proportion of each element before concluding that one mineral is present to the exclusion of the other. The residue may contain talc, sodium fluoride, and wollastonite. The presence of fluorine, as indicated by a positive reaction with alizarin-S[5] shews the presence of NaF. Talc and wollastonite are differentiated by their refractive indices employing bromoform (μ1·59) for identification of talc, and carbon disulphide (μ1·63) for wollastonite.

Group 7. The magnesite is first extracted with HCl, the solution being tested for Mg with quinalizarin or "magneson." If fluorine can be detected in the residue by alizarin-S, cryolite is present, whilst biotite can be found by the use of bromoform (μ1·59) or cassia oil (μ1·6).

TABLE IV.



Group 8. The identification of fluorine indicates fluorspar, whilst enstatite will give a positive reaction to a test for Mg. Carborundum, in the commercial condition, may be easily identified by its colour.

Group 9. In this group, the elements Ca, Mg, Al, Fe, Ti, and Ba, may be identified when present by the use of the flame test, "magneson," alizarin, thiocyanate, tannin, or rhodizonic acid,[5] respectively. The identification of Fe is, however, rather ambiguous since that element may be present as ferro-silicon, siderite, or with titanium in rutile. The presence of SiO_2 in fair amounts would indicate the ferro-alloy, whilst siderite may be extracted with dilute acid and the thiocyanate test applied to the solution. If neither of these procedures yields a positive result then it must be concluded that the iron is present in the rutile.

Group 10. The components of this mixture may be ascertained very simply by examination for Ti, Cr, Mn, and Ni, this latter by use of dimethylglyoxime, and the others by tests already enumerated.

Group 11. The sole member of this group—tungsten—is easily identified by its density and no further confirmation is usually needed. As the carbide is occasionally employed in electrodes, however, and would then fall into this group, it is well to remember that whereas the metal is soluble in hot, concentrated KOH, the carbide is not.

This scheme of separation may be shewn diagrammatically as in Table IV.

Conclusion and Results

The procedures delineated in the previous sections will in the hands of an intelligent worker give quite good results, and, combined with the results of a chemical analysis enable a very near approximation to be made of the composition of the electrode coating. One point must, however, be made, in the identification of the ferro-alloys, we are, as yet unable to differentiate between the high- and low-carbon varieties. It is possible that this differentiation might be attained by correlation of the exact densities of ferro-alloys with their carbon contents, but in practice, this would lead to lengthening of the process already prolonged.

TABLE V.

Electrode No.	Chemical Analysis.		Materials Identified.	Estimated Composition.	Actual Composition.	Error.
1	TiO_2	43·8	Rutile	50·0	49·0	+ 1·0
	SiO_2	13·8	Quartz	5·0	4·5	+ 0·5
	MnO	17·1	Kaolin	16·0	16·5	− 0·5
	Al_2O_3	6·2	Ferro-manganese	16·0	16·5	− 0·5
	CO_2	5·9	Magnesite	13·0	13·5	− 0·5
	MgO	6·2	—	—	—	—
	FeO	4·4	—	—	—	—
	Ign. loss	2·7	—	—	—	—
	C	0·3	—	—	—	—
		100·4		100·0	100·0	—
2	CaO	33·2	Calcite	30·0	30·5	− 0·5
	F	17·5	Fluorspar	37·5	36·5	+ 1·0
	Asbestos wrapping	15·2	Asbestos	15·2	15·5	− 0·3
	CO_2	12·0	Ferro-manganese	3·0	2·5	+ 0·5
	Cr	7·5	Ferro-molybdenum	3·0	3·0	Nil
	SiO_2	4·3	Ferro-chromium	10·0	10·0	Nil
	FeO	3·6	Wood flour	2·0	2·0	Nil
	MnO	2·0	—	—	—	—
	Mo	2·0	—	—	—	—
	Ign. loss	1·9	—	—	—	—
	C	0·7	—	—	—	—
		99·9		100·7	100·0	—

As no method or procedure is worthy of attention until it has produced results of sufficient accuracy, the author appends, as Table V, the results of an examination of two welding electrode coatings, of which the formulæ were known to the supplier but were not divulged to the investigator until after the examination had been completed. It will be seen that the accuracy of the results obtained is well within the preferred limits of percentage composition as normally quoted in patent specifications.

A METALLURGICAL STUDY OF GERMAN AND ITALIAN AERO ENGINES AND AIRCRAFT PARTS.

Readers will be interested to learn that from the proceeds of the book, published by the proprietors of this journal, under the above title, an interim sum of £500 has been sent to the Royal Air Force Benevolent Fund. A few copies of the book are still available at the published price of 10/6 post free.

Light Metals for Marine Engines

By A. J. Murphy, M.Sc.

(*J. Stone and Company Ltd.*)

The great increase in the quantity of light alloys produced and used during the last five years has provoked much speculation on the extent to which these materials will be used when the abnormal consumption for war purposes has ceased. Those who apply these materials to new uses will have the benefit of an accumulated stock of data which was not available in 1939. *Among the many industries which have been studied with a view to the post-war application of light alloys that of ship building has not been overlooked, attention has also been given to Diesel engines and, in a recent paper, before the Institute of Marine Engineers, Mr. Murphy dealt particularly with the part light alloys may play in the marine engine and its ancillaries, an abridgement of which is given in this article.*

THE stream of facts and figures in publications on light alloys emanating from research institutions, private companies and trade associations is as accessible to the marine engineer as it is to the metallurgist, but the metallurgist may be of service in indicating how the various alloys fall into classes, what are the basic characteristics of these classes and what are the factors which should influence a selection from them.

In the category of light alloys it is desired to include both the aluminium-base and the magnesium-base series. It is perhaps a consequence of so much of the discussion on marine applications of light alloys being concerned with the hull and general structure, where resistance to corrosion is the primary consideration, that the service which magnesium-base alloys might render in the engine room appears to have been overlooked. Although the two classes share the feature of low density it is necessary to bear in mind that in other respects there are important differences.

In engine work, the lightness of the alloys of aluminium and magnesium is their most important quality. All the aluminium-base alloys which have mechanical properties of interest for use in engineering components have specific gravities lying between 2·6 and 3·0. The magnesium-base alloys fall within a narrower range of 1·77 to 1·82. A comparison of these with the corresponding values of mild steel, grey cast iron and gunmetal is as follows :—

Material	Specific Gravity	Density 16 cub. in	Density 16 cub. ft.
Magnesium-base alloys	1·8	0·065	112·3
Aluminium-base alloys	2·8	0·101	174·4
Cast Iron	7·5	0·270	466·6
Mild steel	7·8	0·281	485·6
Gunmetal	8·8	0·317	547·8

The consequences which follow the reduction in weight of an engine component depend upon whether its service is static or dynamic. In the first category there are parts such as crankcases, bedplates, gearbox covers, and inspection covers. A saving in weight of these components, such as is achieved by changing from a ferrous material to light alloy, lightens the whole engine to an extent which may be significant or not according to the nature of the vessel. Thus, in a high-speed motorboat, a light-weight engine gives greater scope to the designer in the location of the engine in the vessel and simplifies the problem of strengthening the hull and framing to support the engine. In the large ship it is not so obvious that these considerations may have similar force, although they come to light occasionally. An example was in one of the German pocket battleships, of Washington Treaty days, in which main engine bedplates were reported to have been made of magnesium alloy as a contribution to the all-round saving in weight.

Weight saving might be expected to be of direct appeal in the case of parts such as inspection doors and gear covers on large engines. In the restricted space of a ship's engine room it must be a great boon if a cover which has to be lifted rather frequently and which normally requires two men, or mechanical assistance, to move it can be so lightened in weight that lifting becomes a one-man job.

Pistons

While the foregoing points have special reference to marine engines, the influence of lightness in reciprocating parts is similar in all types of engine. In internal combustion engines the reciprocating component which has received most attention from this point of view is undoubtedly the piston. The author referred to the paper by Mortimer and Paige,[1] who considered light alloy pistons under the headings of alloy composition design, clearances, heat-treatment, and stress relief. Their specification for a cast light alloy piston can be summarised, with reference to these features, as : Y-alloy type or Lo-ex, simplest possible design with a minimum of ribs, clearances at the top edge of 0·008 in. per in. of diameter for Y-alloy and 0·006 in. for Lo-ex ; heat-treatment calculated to give the greatest freedom from stress and the greatest stability at operating temperatures rather than the highest possible strength.

These authors were justifiably at some pains to warn engineers against selecting alloys for light alloy pistons on the basis of the tensile strength at ordinary temperatures or the strength recorded in short time tests at elevated temperatures. They did not, however, continue the discussion to the point of indicating the criteria by which a piston alloy would be selected if experience of its behaviour in service were not available. It may be useful to consider this a little further.

As regards the first point—the strength at the ordinary temperature—the situation is fairly clear. It is the strength at the maximum temperature attained in operation which is significant, and without some knowledge of the rate at which the strength falls off with rising temperature, data relating to the mechanical properties at room temperature are irrelevant.

1 "Light Alloys in Heavy Oil Engines," presented to the Diesel Engine Users' Association, January, 1944.

On the second point it is interesting historically that Y-alloy, which still holds its place in the front rank of piston materials, was selected for that purpose on the basis of short time tensile tests at elevated temperatures. The author did not, however, suggest that the strength in short time tensile tests ought now to be accepted as a reliable criterion for service at high temperature ; at the best such tests can only be regarded as indicating whether a material merits further consideration for such an application.

When we enquire what type of test other than short time tests would bring out most effectively the characteristics needed for a component operating under reciprocating stresses at elevated temperatures, we think of the two ways in which failure could occur by a gradual process under those conditions, namely, through fatigue on account of alternating stresses or through creep under a steady stress at the temperature of operation. The author believes it is the general view, and one which seems natural to him, that to take into consideration only the creep resistance would be an inadequate basis for the selection of a material for pistons. The feature of alternating stress appears to be inseparable from the service of a piston, and the most important mechanical property in this application is therefore the endurance under fatigue at the highest temperature attained by stressed parts of the piston in operation. Nevertheless, if the mean stress of the fatigue cycle is of appreciable magnitude, and expecially if it is a tensile stress, we have the condition of a steady creep-inducing load operating at the same time as the fatiguing forces.

Published data on the creep behaviour and the fatigue properties of light alloys at elevated temperatures are still not numerous, and variations in the testing conditions, e.g., in the number of reversals of stress for which the endurance value is reported, make it difficult to compare the results of different investigators. From the information which is available, however, it is clear that among all light alloys in regular use those of the Y-alloy type are the best in respect of both fatigue strength at temperatures around 300° C. and also in creep resistance.

The published information on creep of aluminium alloys is more extensive. The principal feature again is the outstanding merit of Y-alloy. It is also to be noted that the cast form is distinctly more resistant to creep than the wrought at temperatures of 200° C. and 300° C. both being initially heat-treated to possess the highest strength at ordinary temperatures. This superiority of the cast form in creep resistance is fairly general.

The author cites information obtained from some German work[2] the results of which confirm in a striking manner the all-round superiority of the Y-alloy type aluminium alloy for service in pistons, cylinders and cylinder heads. It is indeed remarkable testimony to the accurate judgment of the late Dr. Rosenhaim (National Physical Laboratory) that the alloy which he first proposed 27 years ago should have performed so brilliantly under the more exacting conditions of testing which have since been developed.

Sometimes the high-silicon alloys are adopted for pistons not because of their low co-efficient of expansion but because they are considered to lend themselves better to the production of a thick, hard film by anodic treatment. This hard film is particularly valuable in reducing wear in the skirt of the piston.

When the mechanical and physical properties of magnesium alloys are examined in the light of the foregoing considerations, the reasons why these ultra light alloys has not found successful application for pistons of internal combustion engines are really seen. The thernal conductivity of the cast alloys which have reasonable mechanical properties at the ordinary temperature is only one-half of the value for Y-alloy, while the co-efficient of expansion is 25 per cent. greater than for Y-alloy. In addition to these unfavourable factors the magnesium alloys in current use all lose strength with rise of temperature much more rapidly than do the aluminium-base piston alloys.

Cylinder Heads

Good thermal conductivity and adequate strength at the operating temperature are also the main requirements for cylinder heads. In liquid-cooled heads there is the complication in marine engines that the most readily available cooling medium, sea water, is corrosive towards the aluminium alloys containing copper or nickel or both, most commonly used where cooling is by fresh water. The difficulty is overcome by using a closed circuit of fresh water circulating through the cylinder-head, with a heat exchanger made of non-corrodible metal cooling the fresh water through the agency of sea water. This would appear to be a troublesome device and the author suggests it would be worth while making a trial with a head cast in a light alloy capable of withstanding the corrosive action of sea water—for instance, one of aluminium-magnesium alloys. such as Birmabright. These have been used successfully for sea-water cooled exhaust manifolds, which present conditions tending to promote corrosion similar to those prevailing in a cylinder head, although in the latter the temperature is higher and the stresses are greater.

If the proposed trial were made it would be essential to avoid contact between copper alloys and the light alloy in the cooling sea water, as this would cause violent galvanic corrosion of the aluminium alloy. There does not appear to be any real difficulty in arranging this, but it should be mentioned that turnings or chips of brass or bronze accidentally finding their way into the water passages of the castings would have very harmful corrosive effects.

Corrosion

It is the author's impression that marine engineers have been diverted from a full appreciation of the service which they might gain from light alloys in the engine room, where the prevailing conditions do not cause severe corrosion, by discussions and experiences of the use of light alloys for ships' hulls, superstructures, and deck fittings which are exposed to sea water and sea water spray and which demand as a first requirement high resistance to corrosion. Aluminium alloys are already used for such engine room components as crank-case inspection doors, gear casings and covers, which are exposed to the atmosphere of the engine room. The alloy most commonly used for these parts, however, is aluminium-silicon, which is notable for its resistance to corrosion ; the success of this application therefore could not be held in itself to demonstrate that corrosive influences are absent from a ship's engine room and could not be used as an argument for permitting

[2] Siebel, Steurer and Stahli. *Z-fur Metallkunde*, July, 1942, **34.7**. pp. 145-150.

the use in and around marine engines of light alloys less resistant to corrosion. The required evidence is provided by steel. Hand rails, floor plates, brackets and levers of bare steel in the engine room are not found to suffer rapid deterioration through corrosion, and on those parts which are wiped regularly with an oily rag a bright surface is maintained without much difficulty. These observations lead to the conclusion that, except for parts in contact with sea water as a cooling medium, the selection of light alloys for marine engine components need not be influenced by considerations of resistance to corrosion. If this view is accepted, a wide range of alloys, magnesium-base as well as aluminium-base, cast and wrought, is available to the designer and builder of marine engines.

Wrought Light Alloys

To avoid making a catalogue of mechanical properties the author makes a selection from the numerous divisions of the subject. Only brief reference is made to the wrought light alloys, attention being directed to instances where they have already found application in the marine engine.

The alloys of aluminium which are used as forgings are generally of the Y-alloy type, which includes the R.R. 56 and R.R. 59 alloys, Ceralumin F and Ceralumin 22. These have tensile strengths of 27 to 30 tons per square inch at the ordinary temperature and retain their mechanical properties rather well at elevated temperatures. The alloys of the Duralumin group have similar, or sometimes superior, strength at the ordinary temperature, but they lose strength more rapidly with rise of temperature and are therefore not suitable for pistons and cylinder heads.

The principal applications of aluminium alloy forgings in the field in which we are interested are for pistons, connecting rods, rockers and rocker-operating rods, fan blades, small caps and covers. Forged pistons are confined to the smaller engines, especially those of aeronautical type. Light alloy connecting rods have proved valuable in reducing inertia. The low modulus of elasticity of aluminium alloys, 10,000,000 lb. per sq. in., as compared with 30,000,000 lb. for steel, necessitates increasing the depth of section to increase the moment of inertia, if equivalent stiffness to that of a steel rod is to be attained, but in spite of this a saving in weight of about 50 per cent. can be effected. The higher coefficient of thermal expansion of the aluminium alloys is an unfavourable factor, where a reduction in the volume of the combustion space as the connecting rod warms up cannot be tolerated. On the other hand, the more massive section of the light alloy rod may prevent an objectionable expansion by diminishing the rise of temperature. It is possible to run hardened gudgeon pins and even crankpins directly in forged aluminium alloy connecting rods, but separate inserted bearings are preferable, if only for the sake of confining the damage to an easily replaceable component in the event of a seizure through some cause such as a temporary failure of lubrication.

Rolled and extruded aluminimum alloys have been used for chequer plates, handrails, fuel pipes and fuel tanks. The alloys containing 3 to 5 per cent. magnesium have been found suitable for these applications and have the advantage over stronger alloys of being easily welded.

Cast Light Alloys

Although it was in the cast form that non-ferrous metals found their earliest application in engineering and military arts, as soon as the equipment necessary to produce forgings, and then to roll and extrude, became available the wrought material was preferred for parts which were of special importance. Forgings gained their place because they were more reliable. Castings were less consistent in quality and there were no means of determining with certainty whether some internal defect was present in the particular casting which it was desired to use. On the other hand it was always true that castings possessed advantages over forgings in some respects. They could be produced with simpler equipment, patterns for castings could be prepared at a fraction of of the cost and in much less time than dies for forgings. If the comparison were to be made with forgings produced without dies then the casting would leave less machining to be done in shaping the finished article. A modification found necessary after series production had begun could be introduced with less delay and dislocation in the case of castings. An advantage of castings more fully appreciated in recent years has been the comparative freedom which they give the designer from the limitations of shape and form imposed by other methods of manufacture.

The renaissance, for it is little less, of castings for critical engineering service has been made possible by new conceptions of technical control in the foundry and by improved means of inspection, especially by the use of X-rays.

The designer wishes to know the properties of his materials in the forms in which he proposes to use them; variation in the mechanical properties throughout a casting will be greater or smaller as the complexity of form and the variations in section are greater or smaller. In light alloys the most important factors affecting the distribution of properties are the degree of local unsoundness and the thickness of sections. By co-operation between designer and founder the influence of these factors can be studied exhaustively in one pattern of casting typical of a class. Once the foundry technique has become established, the corresponding mechanical properties in the important parts of the casting are known, and by the application of radiological examination, coupled, if necessary, with occasional destructive tests, the consistency of subsequent production can be assured. Not the least useful contribution which the founder brings to the consultation is his knowledge of the casting characteristics, or "foundry qualities" of the different alloys available, since one type of alloy by its constitution will be more seriously affected than another by unfavourable circumstances such as thinness of section or restricted contraction. Authoritative information on the subject has recently become available as the result of a co-operative investigation by the Light Metal Founders' Association[3].

Because aeronautical engineering has always been faced with the inescapable necessity for saving weight, it is in the production of aero engines and aircraft that the application of light-alloy castings for stressed components has made the greatest progress. For this reason the author turns to aircraft castings in order to illustrate the standard of quality attainable by the procedure outlined above. Although the examples quoted by the

3 "Light Alloy Castings: Some Notes on the Relationship of the Material and Design." Light Metal Founders' Association, 25, Bennett's Hill, Birmingham, 2.

author are drawn from a different branch of engineering, it is not difficult to recognise the analogies existing between these and certain components in marine engineering construction.

The first evidence cited is a report of strength investigations carried out on a tail-wheel landing fork, having an overall length of 13½ in. and weighing in aluminium alloy 11¼ lb. The alloy used, A.S.M., was chosen since it provides a combination of good casting quality with adequate mechanical strength. The specification properties of the alloy used were :—

0·1% proof stress	Not less than 10 tons per sq. in.
Ultimate tensile stress	" " " 15 " " "
Elongation	" " " 4%

The results of mechanical tests on specimens cut from different positions at one stage in the development of the foundry technique gave the following average properties :—

0·1% proof stress	9·73 tons per sq. in.
Ultimate stress	14·72 tons per sq. in.
Elongation	5·8%

At a later stage in the development of the foundry technique the following average figures were obtained :—

0·1% proof stress	10·98 tons per sq. in.
Ultimate stress	15·78 tons per sq. in.
Elongation	4·6%.

It happens that the same part is made also in magnesium alloy, Elektron A8 to specification D.T.D. 289, which in the standard test bar calls for an ultimate tensile stress not less than 13 tons per sq. in and an elongation not less than 6%. The proof stress expected in this bar is 5 tons per sq. in. Results are given of tests on specimens taken from the same positions as for the aluminium alloy castings. It is noteworthy that although the weight of the casting in Elektron in only 7½ lb., as compared with the 11¼ lb. for aluminium alloy, the average strength in the lighter material is only slightly lower, at 15·32 tons per sq. in., than in A.S.M. aluminium alloy, and the mean elongation is considerably greater. On the other hand it should be noted that the 0·1% proof stress, 5 tons per sq. in. of the magnesium alloy is less than one-half the corresponding value for the aluminium alloy.

Fatigue Properties

The examples which the author describes illustrate the order of the variation in mechanical properties which may be expected in light-alloy castings of relatively simple and also of complex form when a satisfactory foundry technique has been established. It is inevitable that the properties reported are generally determined in the ordinary tensile test, since more elaborate tests would call for more specimens than can usually be provided from a single casting, and a large number of castings is generally not available for sectioning. Opportunities occur occasionally, however, to obtain information on the fatigue properties of specimens cut from actual castings. W. Linicus and E. Scheuer[4] reported the results of their own and other investigators' tests on various engine castings in aluminium alloys. Their findings in respect of average tensile strength and fatigue strengths generally at 20 million cycles were determined on test pieces cut from the casting. The castings investigated were crank cases, radial and in-line, of petrol and Diesel engines, ranging in weight from 16 to 350 kgs., cylinder heads, and test samples of 25 mm. diameter. In general the fatigue strength in the casting shows a smaller fall from the value in the separately cast test bar than occurs in the case of the tensile strength. This is indicated at the foot of a table from which a condensed summary may be prepared as follows :—

For all three alloys examined :—

$$\text{Ratio: } \frac{\text{Average tensile strength in casting}}{\text{Average tensile strength in test bar}} = 0{\cdot}81$$

$$\text{Ratio: } \frac{\text{Average fatigue strength in casting}}{\text{Average fatigue strength in test bar}} = 0{\cdot}91$$

In the author's experience results in general keeping with the above have been obtained in large marine engine castings. In one example the opportunity occurred to make extensive mechanical tests on the material of a scavenge pump piston from a 4,000 h.p. double acting Diesel engine. This was a casting 60 in. in diameter in Ceralumin B alloy. Four specimens were cut from the piston for tensile tests, two from the heavy section and two from the light. Seven test pieces, three from the thicker and four from the thinner portions, were taken for fatigue tests in Wöhler rotary bending machines, with single point loading. The requirements of the specification D.T.D. 287 covering aircraft uses of Ceralumin B. are :—

Ultimate tensile stress	10 tons per sq. in.
Elongation	2 per cent.

The values of tensile strength on a standard sand cast test bar reported on the four specimens taken from the casting, ranged from 82% to 103% of the specification requirement, with an average of 94 per cent. A normal value for the fatigue strength of this alloy in a sand cast test bar, on a basis of 20,000,000 reversals is ±4·5 tons per sq. in. The figure of ±3·85 tons per sq. in. obtained in the results indicates that the fatigue strength of the material in the casting is 86% of the value for the separate test bar.

Effect of Stress Concentration

The fatigue strengths discussed are the values determined on smooth test pieces in which there is no concentration of stress greater than that introduced by the radius of 0·625 in. at the chucking-end of the standard fatigue specimen. It is fairly generally recognised nowadays that for fatigue data to be of much value in the selection of materials for engineering applications they must include some indication of their sensitivity to notches or other features causing local concentrations of stress. The very serious extent to which the fatigue strength of materials can be reduced through notches in the surface is shown by fatigue tests reported by Oberg and Johnson[5] on specimens having a standardised notch in the form of a 60° groove with a radius of 0·010 in. at the base.

In cast aluminium alloys the published data available indicates that the notch sensitivity is in general less than in the wrought alloys. Results by Linicus and Scheuer[6] gave a reduction of 20% in the endurance value of silumin and silumin gamma, while Armbruster[7] reported reductions varying from 7% to 22%, caused by the irregularities of the cast skin.

4 *Metallwirtschaft*, XIII, 47, 48, Nov., 1934.

5 Oberg and Johnson, *Proc. A.S.T.M.*, 37, 1937, 195-203.
6 *Metallwirtschaft*, Nov. 1934.
7 Quoted by Linicus & Scheuer from *Diss. T. H.*, Munich, 1930.

The results of investigations show that forgings and castings in aluminium alloys are not more sensitive to the effect of notches than are the ferrous material with which the marine engineer is familiar. At the same time the necessity remains for the designer and manufacturer to see that there are no avoidable notches, sharp angled shoulders or abrupt changes of section, whatever the material of construction.

Internal Stresses in Light-Alloy Castings

Internal stresses in light-alloy castings intended for engineering applications may be objectionable for two main reasons. The first is the distortion which is liable to occur when a casting having internal stresses is machined, with consequent release of stresses. Deformation of this nature is troublesome when it is desired to machine the castings to close limits of accuracy. The second reason is that the internal stresses may represent a dangerous supplement to the stresses imposed by the external loads of normal service.

Recognised sources of internal stresses in castings are non-uniform cooling of the casting in the mould following solidification, non-uniform cooling in heat-treatment and changes in volume accompanying constitutional transformations.

The determination of the magnitude of the internal stresses in castings, especially if they are of irregular form, is a matter of considerable difficulty and uncertainty. It is possible, however, to obtain guidance as to the effect of various thermal treatments on the internal stresses by a fairly simple experimental process. The author illustrates this by reference to results obtained with cast Y-alloy by a stress relieving heat-treatment.

In alloys which depend for their desirable mechanical properties upon heat-treatment, the effect of a stress-relieving treatment on the strength and hardness has to be considered rather closely. In castings of Ceralumin B, for example, which are normally heat-treated for 8 hours at 165° C., followed by air cooling, the proof stress in tension is appreciably reduced by any subsequent heat-treatment which removes internal stresses substantially or completely. If the change in the width of the gap on extracting the wedge after heating and cooling is assumed to be directly proportional to the remaining internal stress it can be said that while treat- for 2 hours at 330° C. removes 95·2% of the induced stress, heat-treatment for 5 hours at 250° C. only removes 67·2%. On the other hand, the treatment at 250° C. leaves the 0·1% proof stress at 7·35 tons per sq. in., while after heating for 5 hours at 330° C. the proof stress is reduced to 5·16 tons per sq. in.

In magnesium alloy castings internal stresses are generally smaller than in aluminium alloys ; this is to be expected in view of the lower creep resistance and the lower tensile strength of magnesium alloys at elevated temperatures. The times and temperatures appropriate for stress-relieving of unheat-treated aluminium alloy castings are effective also for magnesium alloys. The heat-treatment of magnesium alloy castings does not necessitate quenching, and in consequence " solution-treated " Elektron A. 8 castings, i.e., castings which have been heated for say 16 hours at 400 to 420° C., are practically free from internal stress.

Conclusion

In this paper the author has presented some of the characteristics of light alloys which designers will wish to take into account when deciding what role these materials can play in the further development of the marine engine. It is typical of the principle to which the metallurgist strives more and more to refer his selection and treatment of metals and alloys, that attention has been directed to properties which are not included in the usual specifications governing the inspection of castings and wrought products, but which are of even greater significance in relation to their probable behaviour in service. To know the nominal properties derived from a standard test piece produced under prescribed conditions is not so interesting as to have some idea of how these properties are affected by variations of section, surface imperfections, changes of temperature and the other factors which make up service conditions. It is the responsibility of the metallurgist to provide this information ; in many cases it can be given from existing knowledge, in others experimental investigation is necessary. So far as light alloys are concerned, large programmes of testing are either in progress or are being planned in various establishments. It is important that marine engine designers who are interested in the possible application of light alloys to their own problems, should make known on what features of the mechanical and physical properties of these materials they consider further information is required. In the present paper the author has discussed some of the headings under which that information might be considered, but his treatment of the subject has necessarily been incomplete. He feels that his remarks will have served a useful purpose if they stimulate a discussion which will help the metallurgist to appreciate the attitude of the marine engine designer towards light alloys and his needs as regards technical information.

BRADLEY'S MAGAZINE

After a considerable lapse of time, due to war conditions, it is pleasing to note a further issue of the above magazine has been recently published. The object of the publishers is to bring to the notice of readers articles, notes and thoughts of a technical and scientific character which may be of some interest and guidance in shaping their plans and programmes. This issue describes the moulding of a large acid-resisting silicon iron reaction vessel, and gives useful information on inoculated cast iron. The usual " News and Views " feature is included. A copy of this—the 37th—issue may be obtained on application to Bradley and Foster, Ltd., Darlaston, Staffs.

Ashmore Benson Pease and Co., Ltd., Stockton-on-Tees, have recently issued a brochure giving some information on Meahanite iron castings, which they manufacture. Some excellent illustrations of high-duty and heat-resisting castings are given in weights from ½ lb. to 30 tons. A copy of this brochure may be obtained by applying direct to the firm.

The makers of Dexine and Dexonite have as from January 8 this year changed their name from Dexine, Ltd., to Dexine Rubber and Ebonite, Ltd. As this well-known firm are rubber and ebonite manufacturers, the new title gives a much better picture of their products. Dexine and Dexonite have many uses in industry, particularly in the field of jointings, packings and corrosion resisting equipment, and for 50 years this firm has played an increasingly active part in the application of rubber and ebonite to the solution of rubber engineering and corrosion problems.

Correspondence

Press Forged Pistons

The Editor METALLURGIA.

Dear Sir

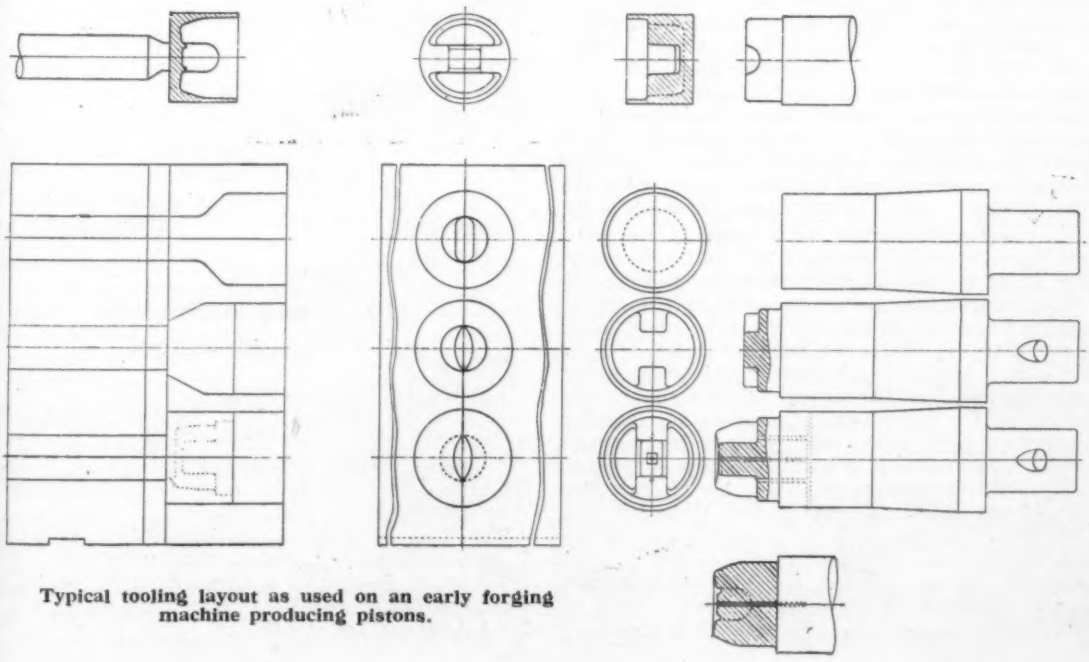
With reference to Mr. H. F. James' comments regarding the technique employed by Messrs. Specialloid Limited in the production of press forged pistons published in your December issue, we note that Mr. James has made reference to the development of pressed pistons having taken place originally in the United States. This is of particular interest to us, as to the best of our knowledge, the first pressed pistons to be commercially supplied were manufactured by Electron Metals, at Stuttgart Germany, for fitment to the 36/220 h.p. supercharged Mercédès Benz car in late 1926. It is also worthy of note that these pistons were manufactured from almost pure magnesium.

Following this practice, interest became general in both Germany and the United States. To this end pistons were produced by the hydraulic press method in Germany, equipment for this purpose being supplied by Messrs. Hydraulik G.M.B.H. of Duisberg, and also by Messrs. Schloemann G.M.B.H., whereas in America the original pressed pistons were, as Mr. James indicates, fabricated on the horizontal Ajax and National forging machines. In this connection it is interesting to note a typical tooling layout as used on one of these early mechanical forging machines as shown in the accompanying drawing. It will be seen that this is a three stage pressing.

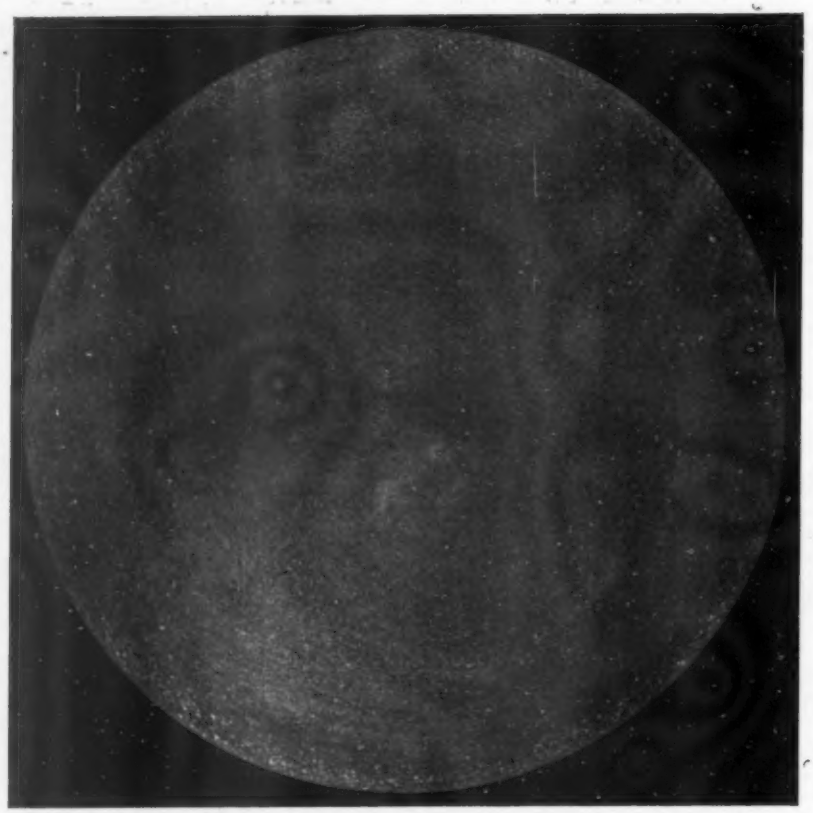
American factories then appear to have discontinued the use of the mechanical horizontal forging machines for piston production in favour of a vertical mechanical forging machine, a typical example being the Maxipress, a product of the National Machinery Company, Tiffin, Ohio, which is operated by an eccentric shaft. With this latter type of press, the early Packard pistons were made with a considerable degree of success.

Also in America the drop stamp has been used to

A pressed piston from a Mercedes engine and a product of Electron Metals, better known as Mahle of Stuttgart, manufactured in 1926 from a magnesium alloy and believed to be the first pressed piston made.



Typical tooling layout as used on an early forging machine producing pistons.



Macra photograph of a typical extruded bar now used in the manufacture of the Company's pistons.

produce certain types of pistons, a typical machine of this type being produced by the Chambersburg Engineering Company, Chambersburg, P.A. This company used a method of close forging pistons on their 6,000 lb. Model "E" drop hammer, whereby the piston was forged to a conical form in the first operation and, in the second operation, closed in on a mechanical press, thus enabling partial undercuts to be produced.

In this country, the Specialloid Company have based their development on the hydraulic press with the control of speed which can be obtained where it is felt that it is a disadvantage to use a crank form of press where the characteristics in movement control to a large degree speed of pressing, whereas, with the hydraulic press, a considerably greater range of speeds can be employed which are, at the same time, for all practical purposes constant during the working stroke.

Mr. James brings up an interesting point with regard to pressing from cast blanks and this is a compromise which, given the desired control, may possess technical advantages over the piston produced from fully wrought material, inasmuch as it is possible to promote stagnation in the flow of the material in the vicinity of the ring pack and thus enable the ring grooves to be left with an equiaxed structure and the stressed parts of the piston to have the advantage of the added strength imparted by the working and, possibly more important still, the consistent quality of the material which, by virtue of the control, can be relied upon to be absolutely free from the defects present in some of the best castings of unsymmetrical form.

Referring now to wrought stock, it is noted that Mr. James indicates that rolled bar was selected in the United States in preference to extruded stock, and here we should like to say that, prior to the War, the Americans had not developed an extrusion process to any degree, but tremendous capacity had been provided for the rolling of light alloys. In consequence, it is not surprising that rolled stock was used extensively. It would now, however, appear that the Americans are leaning towards extruded materials more and more and, in this connection, the Loewy Engineering Company in this country were asked in the early stages of this War to commence manufacturing equipment of this kind in the States. We believe they have been working to full capacity and, from the general reports, it would seem that extrusion is rapidly taking the place of rolling in this particular field.

Reference is also made to the variation in the grain formation in the cross section of extruded bars. This we would say was peculiar to the process in its early stage of formation and was mainly the result of the lack of understanding of the finer technique of the process. In this connection we are showing a macro photograph of a typical bar as used by the Specialloid Company in the manufacture of their pistons, and we can confidently say this depicts the finest basic material that can be obtained.

Yours faithfully,

E. B. GRAHAM,
Technical Director
Specialloid Limited.

Dec. 18, 1944.

Düren and Duralumin

The Editor, METALLURGIA.

Dear Sir,

I should like to correct a slight mistake in the note on page 62 of the current issue. In the first paragraph it is stated that "it was here (Düren) in 1906 that the German metallurgist, Wilm, working at the Kaiser Wilhelm Institute, discovered—quite by accident—the aluminium alloy Duralumin."

The Kaiser Wilhelm Institute (Zentralstelle für Wissenschaftliche-technische Untersuchungen) where Wilm, at the instigation of Count Zeppelin, carried out a systematic investigation of aluminium alloys, was at Neubabelsberg, not at Düren.

As stated by Mr. Horace Clarke, the German Government, which controlled the Kaiser Wilhelm Institute, showed little interest in the invention and handed over the patent rights to Wilm, who offered them to the Dürener Metallwork at Düren, who appointed Wilm as chief metallurgist to develop the invention on a commercial scale. The alloy was named Duralumin from Düren and aluminium, and not from the Latin "durus," or hard-aluminium, as many suppose.

A good deal of the early Duralumin was produced from British aluminium, as there was no German Aluminium Industry in those days, and I had some share in the early development of the alloy and spent quite a lot of time at Düren.—Yours faithfully,

FREEMAN HORN,
Intelligence Officer.
December 28, 1944. British Aluminium Co. Ltd.

The Editor, METALLURGIA.

Deformation of Metals

Sir,

The apologetic manner of Professor Swift's introduction and conclusion is surely unnecessary. The metallurgist has to supply the engineer customer, and I imagine the latter has a pretty fair appreciation of the fact that something of a lull seems to have settled down on the interest taken by metallurgists in those very reactions of the metals which it is their plain duty to understand. In these respects metallurgists will probably own to having but a patchwork of theories leading them to quite arbitrary methods of endowing raw materials with the desired properties of a mechanical nature.

If, in the course of several years, an enthusiast like myself has written upwards of fifty thousand words on a subject of this kind, he may probably be excused in drawing attention to certain of his publications. For, although he may be in a good position to express himself anew in one-tenth of that number of words, he will naturally be in difficulties if called upon to recapitulate to the necessary extent in the course of a single letter to an Editor! I think I can claim to have assisted in inaugurating a "renaissance" of interest by my letter "A Go-As-You-Please Technology" in *The Engineer*, of March 14th, 1941; by my I.Mech.E. paper "A Renaissance of Mechanical Properties," of Sept. 8th, 1942; and by other papers and articles, some of which you have thought fit to bring to the notice of your readers.

Surely a metallurgist would be unable to provide fully satisfactory materials unless and until he has learned to approach matters of the endowment of the properties with an intimate knowledge of those very reactions which today are primarily the study of the engineer! An engineer may certainly have to know more about these reactions than a metallurgist really needs to know as a minimum; but it is impossible to say as yet what this minimum may be. Restricted as regards space for publication, and reassured that brevity and simplicity are the twin souls of "wit," I made my beginning on the reasonable assumption that this minimum knowledge required by metallurgists is a comprehensive understanding of the true stress-strain curve. I have discovered no reason to regret that choice, though my papers to *Engineering* and to *The Philosophical Magazine* (on toughness and hardness respectively) should make it clear that it is necessary to go a little further in order to understand the mechanism of "compound" properties.

Before commenting on more important points in Professor Swift's lecture, I would like to remark that I am personally disappointed to find that "roll pressures," "punch loads" and the like have been relegated to future consideration. An engineer should be in the best position to provide data of immediate practical usefulness from his particular knowledge of the handling of stress in three principle directions—on the supposition of some average hypothetical metallic material. It is moreover chiefly, though of course not solely, these very problems of shaping for use which call for investigation in the light of triple stress reaction. Shaping for use is what I have often described myself as a most important kind of "use"; though in more legitimately styled "use" there is not so much triple stress induction.

The words "hypothetical material" strike a far more important chord, however. This lecture's title suggests that Professor Swift has cautiously restricted his field of philosophical investigation to a single class of solid substances, the metals; yet there is an immense range of types in such a class. Is it really possible, whilst handling substances as diverse as these at one and the same time, successfully to juggle them in and out of the Mohr circles and Lode diagram? Possibly the subject would have been more satisfactorily treated on the basis of one reasonable hypothetical metal. Then, Professor Swift's knowledge of metallic structure in general—of which many a metallurgist would be proud—would have enabled him to indicate the probable trend of divergencies (from the hypothetical case) to be expected in a few types of metallic materials in use today.

One of the advantages of such a plan would have been the laying of an "old ghost," the abandonment of the proverbial search for "the longitude," the dismissal of the possibility of "perpetual motion." For, the average or characteristic metal chosen for examination in the light of all the theories he brings to bear would undoubtedly have been an isotropic polycrystalline aggregate, more or less strain strengthening according to some average curve, and free from those initial irregular strain strengthening effects peculiar to materials like the *unstabilised* steels and wrought iron—(though the existence of the latter effect in no way vitiates the following conclusions).

It is not dogmatic, I think, but only the accepted *literal* truth to say that such an aggregate has neither limit of proportionality, constant modulus, elastic limit, point of commencement of plasticity, nor point of mechanical failure. It follows that it has no definite proof resilience. Whereas it is harmless and most convenient to take liberties with the literal truth for certain purposes, the literal truth asserts itself in no uncertain manner whenever attempts are made to fix a criterion of failure on the basis of a technical elastic limit.

In short, Professor Swift's remark: "There is evidence that certain grain elements become overstrained and set up a process of relaxation in a small way even below the technical elastic limit, . . ." is surely a very serious understatement of the literal truth that the curve shape is *typically* logarithmic, is nowhere straight, and therefore cannot harbour a point or a resilience

marking either the commencement or the full inset of failure. All such fallacies become apparent when the more careful measurements are made. For example: To discover which of the theories of "Failure" on the short list is the most satisfactory.

Nothing less determinate than a fixed proof stress criterion of plastic deformation will really decide between the "short list" theories. If engineers could agree, for example, that a linear permanent strain of 0·002 (measured one minute after release) constitutes the statutory inception of failure and the commencement of plasticity, then it should be possible to compare the rival claims. As there is so widespread a belief in the real existence (in aggregates) of an elastic range separated from a plastic range by an appreciable discontinuity, it is a pity that *open* strain-scale curves of this so-called elastic range are not more often seen in the publications. From the standpoint of a believer in this elastic range of aggregates, probably the most attractive material to quote would be wrought iron or some of the low-carbon (unstabilised) steels in common use. But a study of the open strain-scale curve plotted with the aid of sensitive devices would surely convert anyone to a more rational belief? As to the sudden yield which makes the load-extension curve drop down with such suddenness, is this not because it is quite impossible to control the load application at this point so as to procure a true smooth curve? I deliberately refrain from dogmatism on this latter issue, and would rather beg those who have carefully considered views and good experience on this point to assist me to understand what effective criterion of failure is established by those who try to decide between the merits of the more popular theories.

Professor Swift's argument concerning the impossibility of plastic strain and failure under literally hydrostatic stress is quite understandable; but it might be as well to consider a couple of points here. If there were a slight unbalance between the stresses—due, say, to lack of isotropy, even though the load were literally hydrostatic, then it would be possible for a very small amount of unital *irreversible* work to be done on the material by a stress-difference multiplied by the trifling plastic strain accompanying the (mainly) elastic strain, and that might cause more unbalance. Is it certain that such unital irreversible work would not ultimately effect what amounts to rupture beginning from extremely little initial distortional strain? This may be just one of the points which arise when it is remembered that there is no such thing as completely elastic reaction in the average metal. Then, of course, one is on safe ground again in mentioning that hydrostatic stress in isotropic materials may produce a type of strain which may not interest a mechanical engineer but is nevertheless "strain" induced with stress, much as in the stress-strain curve no doubt, when *allotropic change* takes place under hydrostatic stress. There may not be an example yet known in the case of metals, but there is no reason why metals should be excluded from the operation of a known effect. The linear strain, literally present with any stress not completely hydrostatic, is accompanied by something remarkably like *liquefaction* at glide-planes—only another kind of "change of state" after all. Sometimes we think we have discovered some interesting discontinuity of behaviour in forms of matter, only to find that in reality there is no abrupt change of principle.

It is possible, even probable, that my difficulty with Professor Swift's approach to questions of rupture and plastic deformation reflects my "hysteresis" in following the intricate argument. I personally can see no reason for discriminating between tensile failure and shear failure in the case of metals, since a failure on a plane approximately at right angles to the tensile stress does not seem to argue that shear is not solely responsible for the failure on excessively small surfaces zig-zagging along the plane, perhaps on the shear planes of each individual crystal. I do not think it possible (except by relatively enormous stress induction) to pull atom directly away form atom in a crystal, and it seems to be harder still to separate the atoms of a crystal boundary or slip-band. If a specimen ruptures right across, it might of course give rise to an impression that the shear stress for rupture was greater than the tensile stress for rupture; but what if the shear stress is calculated from the actual superficial area in and out of all the zig-zagging shear planes on the right-across fracture?

It is probably not correct to say that "the plastic range is substantially greater when the system of applied stress is predominantly compressive." This statement is not supported by the curves, and it could not very well be correct if failure for both tension and compression were both identical failure in shear for metals—as I believe. Methods of tube-rolling may require explanation on other grounds less difficult to align with the facts about the average aggregate. The remarks with which Professor Swift introduces his Fig. 1 do not seem to point in the right direction. He refers to "all speeds of straining possible in ordinary testing machines" in connection with the speed effect on the shape of the curves. As a matter of fact the rate of stress and strain induction in the Wöhler test at 2,000 r.p.m. is not much more than 1,000 part of his 4½secs. in the E curve. Warnock and Brennan's tensile impact tests were carried out in about one 2,000 part of his E curve rate. His Fig. 1 curves do not show a really large range of stress induction rate, hence he tends to dismiss the effect of changing rate as almost negligible.

It is difficult to see how plastic strain can be a "rate of straining," though it is always a function of the duration of the load in spite of strain strengthening. Strain strengthening is the result of strain, following it in point of time: Therefore its effect can never *overtake* the tendency of the material to deform, so the tendency passes away according to the "die-away" or logarithmic curve.

I cannot quite agree that "the positions of the origins of the stress-strain diagrams are of no significance" because the proportions of the Mohr circles are of "prime importance." I think that axial deformation in both tension and compression is in both cases the consequence of actual shear. Now, we can produce any stress of the stress-strain curve (and the corresponding degree of strain) by procuring an algebraical sum or resultant of tensile and compressive stresses. But such a method of procuring a net stress would hardly permit us to argue that the origins of the stress-strain diagrams have lost their significance. Why, then, should the net shear stress according to "the proportions of the Mohr circles" enable us to forget the curve origins? I have never yet understood that the net shear stress, so ingeniously forecasted in all planes throughout the material by these circles, was accompanied by shear

strain *other than* that accompanying the same stress on the true stress-strain curve ! I hope I may be put right on this point if I am wrong. It would be most interesting and useful to learn anything possible on such an important point ; for, to a certain extent, the value of the true stress strain curve would be depreciated as a universal standard if, under triple stress induction, the curve shape had to be considered modified by Mohr's circles.

In connection with Fig. 16, it only seems possible to remark that there is no metal really like that, and the nearest to it would be wrought iron and the unstabilised low-carbon steels which are admittedly unsatisfactory for the very reason of their unfortunately sudden yield. However, in some way I have as yet been unable to follow, Professor Swift has converted Fig. 16 into Fig. 17, which is almost characteristic of metallic behaviour, I think. Fig. 15 does seem preferable though, because there is not such a suggestion about it that a perfect hysteresis loop exists. If repetitions of bending were to produce a series of loops, one exactly over the other indefinitely, then indeed it would be true that a perfectly elastic state is attainable. But this does not take place, the curve of each repetition very slightly differs from the last, showing the slight increment of plasticity which is to be found at the lowest "elastic" stress induction.

I take a very lively interest in Professor Swift's unqualified support for that curve : ". . . in which the true stress P/a is plotted against log a_o/a." It might be of interest to mention that, since I independently arrived at the conclusion that this type of strain ordinate was the only one to provide the stress-strain curve with real physical significance, I have been chastened, as well as amused, to discover, first that MacGregor wrote of it in 1937, next that Taylor employed it in 1931, and finally, that it was to be found—as I saw for myself—in "Der Eisenbau," in 1922. How much further back it goes I do not know, but I would be most interested to learn. The 1922 "edition" of this logarithmic strain puts the very recent public claimants for the honours of its first use into a somewhat difficult position. But I can afford to enjoy the joke a little myself because I was rather more cautious than usual in my own public claims to participation in what is certainly an important advance.

Naturally enough, there are all manners of ways in which strain can be reckoned and plotted against stress to provide some kind of a curve ; and there is no doubt that at least the idea of plotting log. a_o/a strain is more than twenty years old, and perhaps a great deal more. Now, a certain contemporary occurrence, which it has been my lot to have experienced, suggests that priority of claim by acceptance date for publication, does not necessarily debar a non-priority holder from making an independent claim of his own. The public are apparently prepared to accept at its face-value the claims of another not so fortunate in his publication date, and a very generous concession that appears to be. Under those circumstances, I do certainly stake a little claim in providing the stress-strain curve with the type of strain which makes it a really significant curve. The investigation which led me to this logarithmic strain was made with the object of providing a curve from which toughness could be read as the area under the curve ; and this is only another way of describing what Professor Swift has said the curve stands for. Is it not important, too, that I succeeded in supplying experimental proof ? (*Engineering*," June 2, 1944).

Finally, to *employ* log. a_o/a strain may be merely to introduce a novelty, the usefulness of which may have escaped notice or the value of which may have been misinterpreted : To *construct* log. a_o/a strain with the sole object of equipping the curve with the feature necessary before it could be significant, is perhaps a more worthy achievement. Has it altogether been decided yet who should be considered "the few" to whom the rest owe so much ? For, I believe this advance to be of really remarkable importance, clinching my own argument that the right stress-strain curve is a complete picture of the "elements" of the mechanical properties.

Yours faithfully,

January 10th, 1945, A. C. VIVIAN (Bedford).

The Editor, METALLURGIA.

Sir,

In commenting on Dr. Vivian's letter I would point out that the lecture to which he refers was intended as a general survey of a subject on which the literature is extensive, and not as a treatise in which each phase could be developed from elementary principles and from experimental evidence analysed in detail. To attempt to convert the lecture into such a treatise, as would be necessary to satisfy Dr. Vivian at all points, would occupy more of your space than you or the majority of your readers would wish or consider necessary. I propose therefore to confine attention to certain major issues and to direct those interested to published sources of more detailed information.

The "average hypothetical material" on which Dr. Vivian would like conceptions of plastic strain to be based is, from the author's viewpoint, defined at length in the lecture. It is an effectively isotropic material with a resistance to plastic deformation measurable in terms of shear resilience and whose subsequent resistance to plastic shear is the same in all directions. It need not, but in general is presumed to, strengthen under plastic strain. The stress-strain relationship for such a material is not prescribed in form, but it will be of the same form for any one material under all systems of stress if plotted in terms of the representative stress q° and representative strain ψ_o as defined in the lecture. Divergences of actual metals from this hypothetical material are discussed in p. 55, par. 5, and in relation to Figs. 5 and 14 and even divergences within the technical elastic range are mentioned in p. 55, par. 2.

Judgment on Dr. Vivian's claim that the stress-strain curve is "typically logarithmic" without any linear portion can safely be left to your readers in the light of Fig. 12 and of a mass of published information. In any case this claim is difficult to sustain for a strain-hardened material which returns *by a different route* to the same curve as it would have followed from the annealed state. It is submitted that the relationship is much better conceived as linear up to the point at which plastic strain becomes significant (0·002 if Dr. Vivian wishes). The resilience at this point can then approximately define the resistance of the material to plastic flow.

The author's statement that "the plastic range is substantially greater when the system of applied stress is predominantly compressive," which is disputed by Dr. Vivian, is based on the fact that "the effective plastic range is limited at one end by the conditions of

elastic breakdown and at the other by the conditions of ultimate rupture," on the submission that elastic breakdown when properly defined is independent of the system of stress, and on a cloud of witness that the representative stress at rupture is not independent of this system but is greatest under predominantly compressive conditions. Consideration of the type of fracture is merely introduced to illustrate this point, but all experimental evidence supports the contention that fracture follows a plane or surface on which the critical stress has its greatest value. In this connection it should not be necessary to point out that in tension the maximum shear stress is only one half the tensile stress, and that this is true whether the calculation is made on "zig-zagging" or continuous "shear planes."

The Mohr circle diagram is a graphical means of analysing the stresses or strains in different directions and, being based purely on mechanical and geometrical principles, is applicable to any material whatever its properties. The most complete account is still that originally given by its author in *Der Civilingenieur*, 1882. The Lode diagram (ref. *Zeit. Phys.*, 1926) is merely a means of plotting experimental results obtained with different stress systems and is likewise applicable to any material.

The conception of plastic strain as a "rate of straining" dates back to St. Venant and Levy (*C.R.*, 1870) and has been employed by Sachs (*Spanlose Formung*, 1937) and others in more recent times. Comparisons of the various hypotheses of inception of plastic flow will be found in several textbooks (e.g.—*Case, Strength of Materials*). The method of plotting true stress-strain curves favoured by Dr. Vivian can be traced back to Ludwik (*Tech. Mechanik*, 1909, Plate 1, Fig. 1) but it has not hitherto become popular, probably because it involves a modified testing technique. The form of strain-hardening characteristic suggested in the lecture, according to which the true strain is plotted logarithmically, would have the advantages detailed on p. 59 and could be applied under any system of applied stress. But under most conditions of test the one curve is easily derived from the other and any assistance which Dr. Vivian could give in securing the general adoption of the modified technique in research laboratories would certainly place him in the credit of all concerned with the interpretation and correlation of experimental results.—Yours faithfully.

H. W. SWIFT.

The University of Sheffield,
Departments of Engineering,
15th January, 1945.

The Editor, METALLURGIA.

Press Forged Pistons—(*Contd. from p.* 130).

Dear Sir,

Mr. Graham's response to my notes invites little further discussion of the technique employed for press-forging pistons. It should be unnecessary for me to state that my comments related specifically to American and German practice and experience before the war, and not to the technique adopted by Specialloid, Ltd. The Elektron pistons referred to were neither a practical nor a commercial success, and, I think, could scarcely be described as prototypes of the forged aluminium alloy pistons subsequently developed.

Referring to the paragraph discussing cast forging stock, it is not clear why disposition of the cast structure would necessarily be equiaxial; nor would such a structure seem to be especially advantageous. Mr. Graham's comments on extrusion practice in America at the outbreak of war are hardly justified, since, in fact, extrusion technique had been brought to an advanced stage of development in America some years earlier.

The macro photograph certainly shows a good structure for forging. It was but a comparatively short time ago, however, that the relatively high incidence of forging defects which were attributed to variations in grain formation observed on the cross-section of extruded aluminium alloy stock, induced the drop forgers in this country to propose that every batch of such stock be required to pass a standard forgability test.

In case I have missed any points of importance in Mr. Graham's letter, I must confess to having been somewhat baffled by his syntax.—Yours faithfully,

H. F. JAMES.

London, W. 1,
January 18, 1945.

Jet Propulsion for Aircraft

THERE seems to have been created an erroneous impression regarding the development of jet propulsion as applied to aircraft. For some reason there is a tendency to suppress Great Britain's share in this development. Much of the credit should go to the British Thomson-Houston Co., Ltd. This company was first approached by Air Commodore Frank Whittle (then a flight lieutenant) in September, 1931, in connection with a paper he was then preparing on "The Turbo-Compressor and Supercharging of Aero Engines." The experience of the company enabled them to supply data which were incorporated in the paper. During 1933 the company carried out a comprehensive investigation of the possibilities of various gas turbine cycles from the point of view of the use of this type of prime mover for generating power.

In January, 1936, the company was approached by Air Commodore Whittle in regard to the development of a jet propulsion engine for aircraft and later Power Jets, Ltd., placed the contracts with the company for the manufacture of the jet engines under Air Commodore Whittle's supervision. The first experimental aircraft was fitted with a jet turbine engine manufactured by the B.T.-H. Co., and it made its first flight in May, 1941. A similar engine, also made by B.T.-H., was sent, together with the drawings, to the United States in September, 1941, for the American General Electric Co. to study and copy, after information concerning the development had been disclosed to General Arnold, of the U.S.A.A.F. Since 1941, enormous manufacturing developments have taken place in this country and in America, in which connection many British aero-engine and aircraft manufacturers could be cited.

Erratum

In the article entitled "Volumetric Determination of Copper in Aluminium Alloys" on page 10 of November, 1944, issue, the fourth line under the sub-heading "Method" should read :—"zinc acetate solution prepared by dissolving 80 g. ZnO".

Industrial Research and Development

By W. C. Devereux, F.R.Ae.S.

Director Reynold's Rolling Mills, Ltd.
Chairman of International Alloys, Ltd.
Chairman and Managing Director of High Duty Alloys, Ltd.
Chairman and Managing Director of Ocean Salts (Products), Ltd.

The war years have shown how closely industrial progress is linked with research and it is fortunate for this country that a number of our people had sufficient foresight before the war not only to press for intensified research, but to provide facilities for it to be carried out. Prominent among them was Mr. Devereux, who presented a paper at the recent meeting of the British Association from which the present article has been abstracted. It will be noted that applied research is stressed so that industry may develop its manufacturing processes and products with the minimum of delay.

THE realisation of the tremendous tasks which lie ahead of our industry in the post-war years and of the vital necessity to increase our national wealth at more than twice the rate at which it has increased hitherto, has thrown the need for vastly increased industrial efficiency into high relief, for it is upon industry that we must depend in large measure to meet our obligations in respect of social security, full employment and the many other calls upon our wealth that we have undertaken during these past few years.

The Government has shown awareness of the problem, and the Chancellor of the Exchequer has recently made reference to the subject, promising tax-concessions calculated to increase expenditure on the expansion of facilities for research. It is also noteworthy that in all of the post-war plans published recently mention is made of the need for intensified research activities.

As one who has long advocated and practised the application of scientific methods to industrial problems, I cannot but be extremely gratified by this rather sudden awakening to the value of industrial research, but, at the same time, feel that at least a part of this new enthusiasm is engendered in some by a feeling of desperation arising from the realisation of the difficulties which will confront us after the war.

Those who have experienced the workings of scientific research will know that it is not going to solve all our problems overnight, it takes time and money and then more money to develop a new material or a new process. it calls, above all, for faith and confidence that it will, in the end, produce the goods, despite the set-backs which appear from time to time. I hope that this new support from all quarters for industrial research represents a genuine and deep-rooted conviction in its fundamental importance to our national economy and not mere lip service to a new idea, to be cast aside when capital and revenue are in short supply.

Of late the appearance of the inevitable reaction to this sudden new popularity of research is noticeable. It is being said, for instance, that some of the foreign research, which has been held up to us as a shining example in the past, is mere window-dressing. This may be true to some extent, but this should not worry us in the least. There is nothing wrong in window-dressing. In fact, I think that we, as a nation, have sadly neglected this important aspect of foreign trade promotion in recent years. We have been fortunate indeed that, despite this neglect consciously to display our wares in the international shop window, this country has continued to produce scientists of world-wide reputation whose work has done much to maintain the international good will which we enjoyed in the past.

The bulk of industrial research is carried on in the laboratories of industrial firms, and, to a lesser extent, by the Research Associations and Government establishments. Of late there has been a tendency for some university research departments to carry out work for industry. This latter development is one which I suggest should be closely watched, for if it means that the fundamental research work of these universities is being relaxed in order to accommodate applied research, then industry will be the loser.

Our universities might well take stock of the new position created by the demands of industry for fully qualified scientific research workers and engineers, particularly in equipping them for the higher posts in research management and administration. At the present time there is undoubtedly a lack of suitable men for these posts—in some way a scientific education seems to carry with it a false superiority to business matters.

This country has certainly not been backward in its contribution to pure science and fundamental research. It is in the application of the work of our university research workers that we have lagged behind. This is due in part to a lack of enterprise on the part of industry and in part to the shortage of properly trained industrial scientists and technicians. The universities must turn out a sufficient number of scientists at the same time as great advances are being made in pure science in order that industry will be provided with men qualified to interpret the new knowledge. But industry must play its part by making scientific posts sufficiently attractive to ensure a steady stream of the right type of man through the universities.

The brilliant work in metallurgical physics which is being carried on by Dr. Hume-Rothery at Oxford will have far-reaching effects on industrial metallurgy, but, unless the industry can enlist a sufficient number of men, with the right kind of qualifications, to apply these new theories to practice, the benefit will go to other countries.

In the light alloy fabricating industry one of the principal research objectives in the development of alloys with improved properties and, in particular, the

improvement of those properties which influence behaviour under the peculiar conditions encountered by various components under service conditions. This objective calls for the closest possible liaison with the designers and engineers using these materials and for the continuous improvement of the technique and apparatus for testing.

Since the introduction of Duralumin in the early part of the century and the subsequent development of " Y " alloy and the R.R. series, a steady rate of improvement has been maintained in the properties of the light alloys, but this has continued along empirical lines largely by the processes of trial and error. The important work of Dr. Hume-Rothery and the increasing data on phase-equilibrium diagrams which is becoming available, already point the way to far greater and more rapid developments in the future.

It must be remembered, however, that theoretical considerations alone cannot govern our progress. Very often they must give place to technological factors. Alloys of very greatly increased strength may be discovered, but it may be that they will require specialised treatment in their fabrication, or they may be found subject to stress corrosion and intercrystalline corrosion or for one reason or another their cost may be prohibitive.

Whilst ten years ago the " ceiling " of tensile strength in light alloys was in the region of thirty tons per square inch, gradual development has raised this figure to forty tons per square inch. I do not visualise any great increase on this figure in the immediate future, but it should be borne in mind, in order to retain a balanced outlook on this question, that, for the majority of uses, the lower strength alloys are likely to predominate in production owing to their greater ease of fabrication.

The field of casting alloys has been characterised in recent years by the conflicting claims of the high strength alloys and the lower strength but more easily cast alloys. Close study and development of foundry methods has now cleared the way for a far greater utilisation of the higher strength casting alloys.

The technique of X-ray diffraction is finding valuable practical applications in the determination of locked-up internal stresses, particularly in forged components. It has long been realised, of course, that locked-up stresses can limit, to a very low figure, the permissible external stresses which may be applied. In these circumstances it was clear that the performance of engine components could be improved if the extent of the locked-up stresses could be determined accurately. To deal with this an X-ray crystallographic method* was developed by means of which it is possible to survey a component and to plot the internal stresses present at various points in it.

This method of investigating the problem has yielded a great deal of information on the part played by heat-treatment on the distribution of internal stresses, and the problem has been resolved into one of establishing suitable methods of heat-treatment to give a predetermined stress distribution in the components. As a direct result of this ability to study the magnitude and distribution of internal stresses designers can with more confidence use mechanical test figures of the material for design purposes.

Another considerable advance has taken place recently in the study of fatigue. Improved fatigue testing methods, especially those for operation at elevated temperatures gives the designer the means of comparing the fatigue properties of a new material with one of known performance under fatigue conditions. These improved methods have undoubtedly played a very important part in the rapid development of the jet engine.

Great interest has been shown recently in a new approach to the study of materials under vibrating conditions, using the property known as damping the property of materials which controls the amplitude of vibration at resonant frequency owing to the absorption of energy by the material itself. It was thought at one time, that this factor was of importance in structures, but measurements of the actual damping of alloys show that at low amplitudes, this is so small as to be insignificant as compared with the damping which occurs at the joints in the structure.

*Frommer and Lloyd, *J. Inst. Met.* **70** (3), 91-124.

Economic Research

In addition to the kind of laboratory research work usually referred to as industrial research, the newly emerging techniques of applied economic research and market research should be included.

Market research is rapidly assuming an important function in industry, especially in relation to other forms of industrial research and development. On many occasions this country has failed to exploit fully the results of scientific research work because we have failed to realise the far-reaching effects of new inventions or, realising them, have not had the courage to lay out the capital necessary to achieve a sufficiently large output to meet the demand, thus allowing others to get into the market on the gound floor.

The importance of a proper approach to the problem of the development of a laboratory process into a manufacturing routine cannot be too strongly emphasised. In the past this important link has been omitted in many industrial organisations, and it is still not exceptional for a new process to be passed directly from the laboratory to the works with an inevitable interruption of the smooth flow of production and usually an unnecessarily long delay in getting the new process to work on a production scale. This also has undesirable repercussions on the research laboratories for the temptation is strong to do development work there so that the process may succeed when handed over to the works. This results in a diversion of the research efforts.

As a supplier of structural materials, experience shows that it is not enough merely to develop a material showing greatly improved mechanical properties. It is necessary to go very much further than this. A great deal of design data for the use of this material must be supplied. Unless this is done it may take five or more years before sufficient practical experience is gradually built up to exploit the properties of the material fully.

Much remains to be done to encourage all branches of industry to increase their research effort. The supply of men trained for industrial research and development work must be increased without delay, and we must not allow the technique of the rapid application of new scientific knowledge, which we have learned under the urgency of war to fall into disuse. Only by the fullest and most rapid application of research in the sciences, in engineering, and in economics to our industries can we surmount the great difficulties which will confront us in the post-war world.

Fuel-Gas in the Light Alloy Industry

By H. Truman
(*The Power-Gas Corporation, Ltd.*)

Heat plays a vital part in all metallurgical operations and has, during recent years, presented many problems to manufacturers. Fuel oil has been in short supply for some years and towns' gas supplies could not satisfy the demands of industry for the increasing need for heat. It is not surprising, therefore, that considerable attention has been given to producer gas as an alternative fuel and in this article attention is directed particularly to the development of producer gas plant for the light metal industry.

FOR the purpose of this article, the light alloy industry is considered to comprise the production of aluminium and magnesium from ores, their alloying, and the processing of the metals and alloys, such as the manufacturing of castings, forgings, pressings, extrusions and rolled products. Practically every one of these operations involves the consumption of fuel, so that the form which this fuel takes is of primary importance. The growth of the industry is closely allied with the development of aviation and probably 90% of the metals and alloys are used directly for aircraft production. The progress during war years is illustrated by the recent statement that enough aircraft are now built in a few days to satisfy one year's pre-war aviation needs.

This industrial expansion had to be accomplished in a brief space of time, and when one of the fuels hitherto used, fuel oil, was in short supply. Town's gas, of course, was also widely used, and it became obvious that existing supplies in this country could not cope with the demands of the industry. To ensure that the regular output of essential components should not be interrupted, factories were dispersed, and new factories were built in non-vulnerable areas or areas isolated from other possible targets, often where town's gas plant would in any case have been inadequate. The enlargement of a town's gas works is a lengthy and expensive matter; moreover, large quantities of suitable coals have to be transported to such works, where only about 75 therms of useful gaseous fuel are produced per ton of coal, the bulk of the thermal value being recovered as coke, for which, in many cases, there would not be a local demand.

In deciding upon a suitable alternative fuel, it was natural that the choice should fall on producer gas. Advantage could be taken of the simplicity of the gasification process, and plants of large capacity could be quickly manufactured and installed, capable of giving the necessary flexibility without having to provide storage capacity. In suitable equipment, producer gas may be successfully manufactured from almost any solid fuel, including those generally considered of little value, and in any part of the country with the minimum demand on an already overtaxed transport system. Dependent on the fuel gasified, thermal yield of producer gas is from 180–260 therms per ton.

As a result of these considerations an extensive programme was inaugurated for manufacture and installation of producer gas plants in a large variety of sizes and types to provide clean cold producer gas. Plants built included small emergency units with an hourly output of 5 therms, up to multiples of large fully mechanical units to give in a single factory a total of 25,000 therms per day. A firm of specialists in the design and fabrication of such plants, the Power-Gas Corporation, Ltd., has during the past three years installed plant of a total daily capacity of nearly 200,000 therms (approximately 130,000,000 cubic feet per day) for the light alloy industry alone. In this capacity, roughly 40% is derived from various grades of anthracite, 50% from a wide variety of cokes and 10% from bituminous coals.

Whilst slight changes were needed at much of the consuming equipment, and the technique of the furnace and plant operation had to be modified, there has been no loss in production during the change-over in old factories. In the setting to work of new factories with, for the most part, a shortage of labour and an absence of experienced personnel, no time was lost in getting into production, and the novices became accustomed to the use of producer gas. The design of the plant had to be such that operators who had never seen or heard of a gas producer, were able to acquire the necessary operating technique in a few weeks. Fig. 1, showing the different fuels making up the thermal load at one factory over a period of three years, illustrates how effectively the change-over can be made.

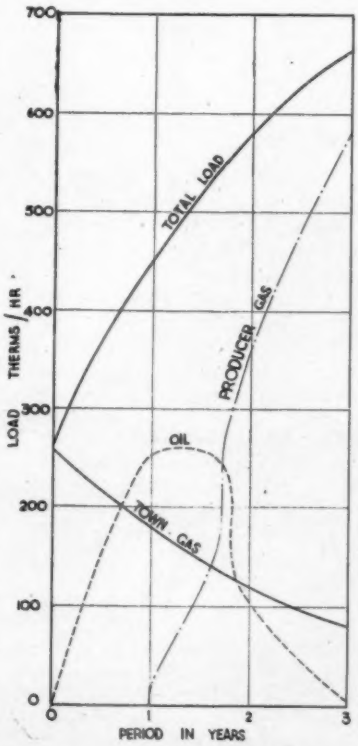


Fig. 1.—Chart showing make-up of the thermal load in one factory.

Before going on to describe a typical plant used in the light alloy industry, a brief review of the uses of producer gas in different operations will be of interest.

Metal Production

Magnesium: In every process for the production of magnesium, whether from carnalite, magnesite, sea water, dolomite, brucite, and whether by the electrolytic

isolation or the thermal reduction process, the fuel requirements are high, and a cheap but convenient form of heating is therefore essential. In most of the larger factories for producing the metal and its alloys in this country, the fuel used is producer gas, and several large-scale producer gas plants have been installed in the past 10 years. These installations serve to provide the heating medium in all phases of production, i.e., for the calcination of dolomite in gas fired kilns, the drying and briquetting of magnesia, the dehydration of magnesium chloride before electrolysis, the heating of retort furnaces used in the thermal reduction process, etc. The metal thus produced, the physical state of which is dependent upon the manufacturing process used, is melted in pot type furnaces, purified by the addition of fluxes, and cast into ingots. Further treatment for production of alloys is carried out in similar furnaces, the alloying metals being added to the magnesium in the pots.

Aluminium: The production of aluminium is essentially an electrolytic operation, and hence is confined to areas where power is cheaply available. In the recovery of this metal from scrap, however, the furnaces are often coke-fired rotary or open-hearth types. In many cases where such furnaces were oil or town's gas heated, the conversion to producer gas has been made and in all such cases the economy of melting compares most favourably with that originally appertaining. The purified metal is cast into ingots of shapes and sizes dependent upon the after use of the metal.

Working of Light Alloys

Foundries: For the melting and superheating of the alloys, drying of cores and moulds, heating of dies, stress relieving and ageing furnaces, sand drying, ladle heating and for supplying the heating for air conditioning systems, plants of a total capacity in excess of 70,000 therms per day of the type described have been installed in the past 5 years. Whilst there were in old-established factories, certain teething troubles due to the different flame characteristics and operational conditions, these were soon overcome.

Sheet and Section Mills: Many large new factories are entirely dependent upon producer gas for their fuel needs, and the usual applications are being easily worked, furnaces for billet heating for rolling and extrusions being controlled by automatic instruments of the standard design. Other uses include automatically controlled heat-treatment furnaces, roll heating, remelting, all the applications of modern mills and space heating.

Stampings and Forgings: Producer gas is the only source of fuel in many factories for billet heating in furnaces of both direct and radiant tube types, die heating, heat-treatment of finished products, remelting of scrap and space heating.

Manufacture of Fluxes used in the Melting of Light Alloys: Factories for the production of fluxes previously imported, are entirely dependent upon producer gas for use in process furnaces, boilers, and evaporators.

General: At many locations where supplies of town's gas do not exist, or are limited, the canteen cooking and baking are being successfully carried out with only slight modifications to standard designs of equipment. In other subsidiary operations allied to the industry, producer gas is being used with success, e.g., toolroom furnaces are being operated at high temperatures with slight modifications to the standard burners. Much equipment, particularly in established factories, was altered only so far as would make the process workable (not necessarily to as high an efficiency as might be obtained) and yet not impair the efficiency of such equipment if a switch to an alternative fuel had to be made for any reason.

Where it has been found that producer gas can be produced and used at a lower cost than town's gas or fuel oil can be purchased, then as the furnace equipment fails it is replaced by equipment specially designed for the different characteristics of the gas and a still more economic working is obtained.

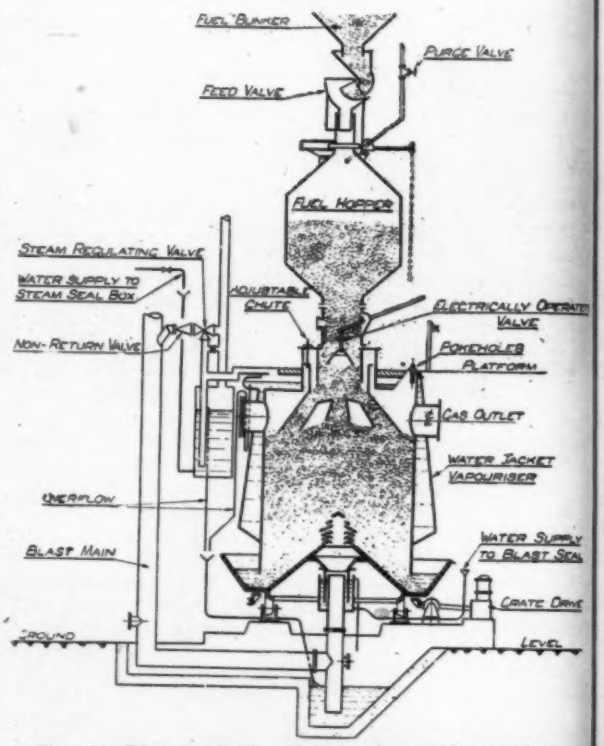


Fig. 2.—Diagrammatic section of a self-steaming gas producer with gravity fuel feed, mechanical grate and automatic ash discharge.

Application of Gas to Furnaces

Obviously it might reasonably be expected that there should be little or no difference in the thermal requirements with any suitable gaseous fuel, when design of furnace is chosen at the start to suit that fuel. Consequently the most economic is that which can be most cheaply produced.

There are two main categories into which heating applications can be broadly classified viz., metal melting and heat-treatment. In the former case, conditions are so varied that results must differ over a fairly wide range dependent upon the foundry practice, type of metal being melted, type of melting pot, weight of charge, time of melting (usually required to be as short as possible), etc. The amount of superheat is a particularly important factor, for on one application with town's gas firing where 36 therms per ton are consumed in the ordinary melting of aluminium, the consumption is over 50 therms when superheating by 50° C. This same

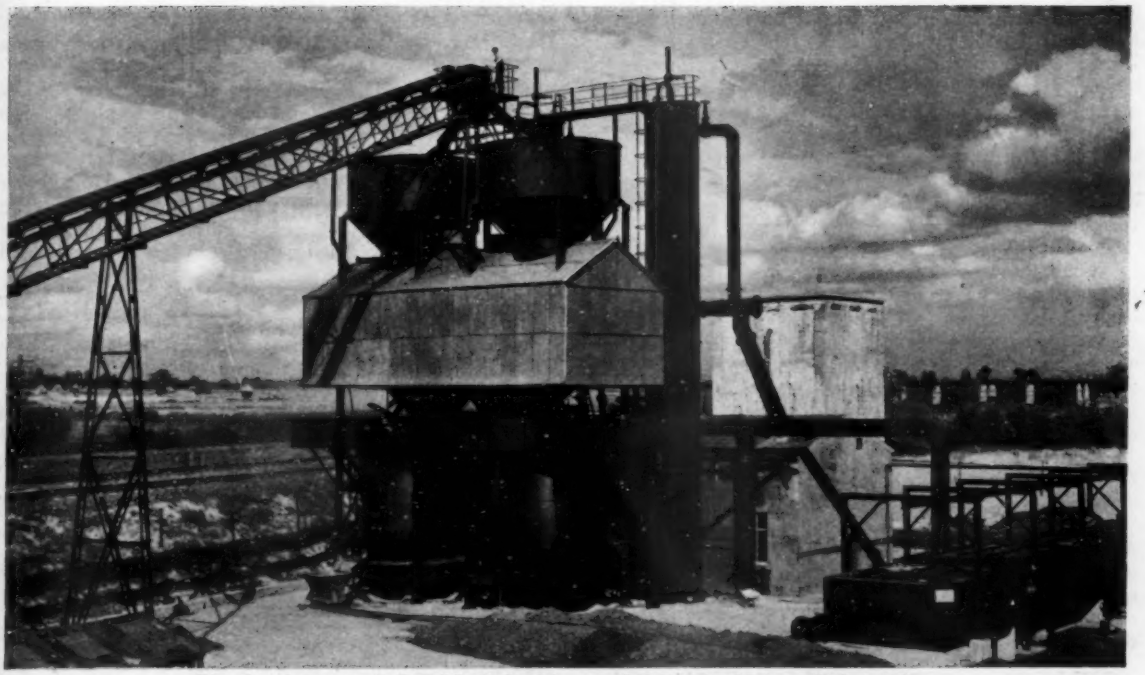


Fig. 3.—A two-unit P.G.M. 10 ft. 6 in. producer gas plant gasifying coke.

application without superheat absorbed 38 therms per ton when the burners were modified to use producer gas.

For the melting of magnesium in cast steel pots with charges of 300 to 550 lb., producer gas consumption was established at 55 to 57 therms per ton of metal, with town's gas practically the same at 56 to 60 therms. In this case the respective furnaces were designed for the particular fuel gas. For melting aluminium scrap in larger bale-out furnaces designed for using town's gas, using plumbago pots holding 1,200 lb. per charge, requirements were 68 therms per ton of metal. The same furnaces with burners only modified for producer gas needed 73 therms per ton of scrap melted, and to improve upon this figure it would be necessary to design the furnaces correctly for using producer gas, with suitable burners and proper combustion space.

As regards the usual heat treatment operations, there should be very little difference, whatever fuel gas is used. Producer gas is perhaps slightly more effective in low temperature applications but requires air or gas preheat at higher temperature, 1,100° to 1,350° C. If equipment is converted from either gas to the other, results are seldom as satisfactory with the substitute, as in the case of equipment specifically designed for the purpose. Accurate data about heat-treatment operations generally has not yet been collated, but it would certainly seem that improvement of efficiency is a field which would well repay careful cultivation.

A Typical Producer Gas Plant

A typical P.G. mechanical gas producer plant, of which so many are being used in the industry, consists of producer(s) with fuel handling equipment, gas cleaning plant, water cooling and pumping equipment and pressure regulator gear, generally as illustrated in Figs. 2, 3, 4 and 5.

The self-vapourising producer is fitted with automatic gravity fuel feed, a revolving grate and continuous ash discharge, as shown sectionally in Fig. 2. It consists of a stationary water jacketted cylindrical shell with water sealed base which carries the grate. This grate is driven at speed which can be infinitely varied to suit load conditions and characteristics of the fuel gasified, the ash being automatically delivered over the side of the bowl into suitable receptacles for removal to waste. The vapouriser jacket surrounding the producer shell serves to generate sufficient steam for gas production, to prevent the formation of clinker at the producer sides and to keep the producer top cool.

The fuel to be gasified is emptied from trucks into a hopper at ground level, and elevated by skip hoist or inclined belt conveyer to the overhead storage bunkers, which carry a day's supply of fuel. The skip hoist is fully automatic, continuing to elevate fuel from the pressing of the start button until the pressing of the stop button. Simple adjustment for the different density of coke or anthracite can be made by the delay control for filling and emptying the skip. Capacity of the equipment is arranged so that the elevating of fuel can be done during daylight hours. For multi-unit producer gas plants an angle type of hoist can be used with arrangements to tip into any bunker as required.

From the bunker fuel is discharged into the producer through the gravity fuel feed, consisting of a hopper placed between the bunker and the producer, and fitted with interlocked feed valves. The fuel in the hopper, representing several hours' supply, forms a continuous column through the producer, its flow being self-adjusted to the rate of fuel consumption. A multi-chute distributor, which can be raised or lowered to suit the fuel used, ensures an even distribution to all parts of the firebed, both of quantity and grading. An electrically

operated hopper bell is actuated at regular intervals to keep the fuel in motion and assist it in its passage from the hopper to the producer. At such times as the hopper is empty this bell valve automatically closes, giving a visual and audible warning to the operator that a fresh charge of fuel is required. When the valve is closed the hopper is isolated from the producer for recharging ; in the meantime the fuel contained in the internal distributor maintains constant conditions in the producer.

The hot gas from the producer, at a pressure controlled by a governor of simple bell or more elaborate type, passes to a vessel for cooling and washing to reduce the tar and dust contents. This vessel consists of a cylindrical steel tower closed at the top, and water sealed at the bottom. Cold water is fed in at the top of the vessel and passes contraflow to the gas over a number of alternately placed cones and discs. Effective washing and cooling is achieved in a comparatively small space. The water leaving the plant is passed over a cooling tower, and pumps are provided for the recirculation system to and from the cleaning plant.

From the washer the gas is subjected to further cleaning by means of a centrifugal cleaner which consists of an electrically driven impellor revolving at high speed and mounted in a gas-tight casing in which the gas is brought into contact with a finely divided liquid spray and is boosted to a pressure sufficient to force it through dry scrubbers. In these vessels, which are rectangular mild steel boxes fitted with timber grids to carry purification material, the gas is still further cleaned and the H_2S content is reduced. The cool, clean, dry gas is then passed to a booster which gives the pressure necessary for distribution to the point of consumption.

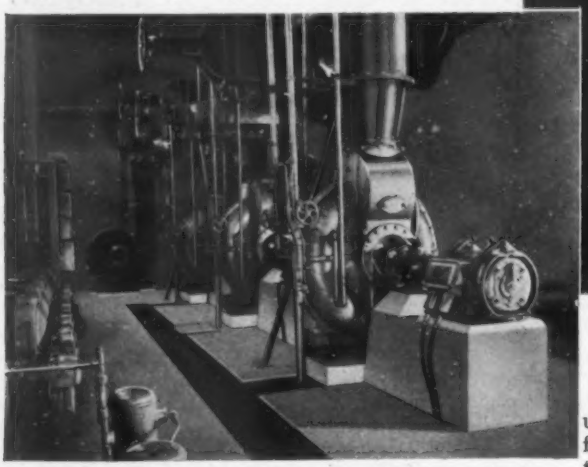


Fig. 5.—Auxiliary machinery of producer gas plant.

Automatic gas pressure regulation is usually incorporated to maintain a steady pressure in the main, especially when the load is of a fluctuating nature. Recording and indicating instruments are fitted to assist the economic and efficient working of the plant, which is practically automatic in operation, and requires little attention. Occasionally the producer fires must be examined and the hopper recharged with fuel about once per shift. If operation is continuous, variations in the demand for gas from 25% to 110% of full load are satisfactorily dealt with. At week-ends, or such times as gas is not required, a plant can be put on standby and left unattended for a day or so at a time, after which gas is quickly available to meet demands.

In some cases the reduction of sulphur impurities is necessary, and is in fact practised at many plants. The P.G. process combines this purification with the stage of gas washing and cooling, and makes use of the same equipment. The gas is simultaneously washed and cooled and purified in the cooler washers by a weak alkaline solution. The hot solution is then passed to the cooling tower and the revivified cooled solution is recirculated to the washing system. The cost of materials for operating such a process is only of the order of 0·03d. per therm. The gas is then passed to the dry scrubbers where the H_2S content is further reduced until it is between 5 and 7% of the quantity originally present. In small installations, for still finer purity, the " Docking " dry purification system, which is operated on the principle of town's gas purification, is applied and for very small gas quantities as used in canteens, small standard five therm purifiers are widely used.

Fig. 4.—Instrument panel of producer gas plant.

Producer Gas Plant Operation and Costs

During the test on a plant of the type described, when using Welsh anthracite of a grading ¾ in. to ⅝ in., the following results were obtained : the producer in question hadbeen working for some months prior to the test period.

Duration of test	98 hours.
Gas produced	177,950 cu. ft./ton of dry fuel.
Cold gas efficiency	81%
Typical gas analysis	CO_2, 4·5% ; CO, 26% ; H_2, 15·6%; CH_4, 1·6% ; N_2, 52·3%.

Cal. value—148·6 B.Th.U. gross per cu. ft. at 30 in. Hg. and 60° F.
Gas produced per hour—165,000 cu. ft. at 30 in. Hg. and 60° F.

In a factory producing light alloys where a two-unit plant with a rated capacity of 400 therms per hour is operating continuously at 75° C. load factor, the costs of producing gas are as follows :—

	Cost of gas, pence/therm
Coke (at 54/- per ton)	3·150
Labour (2 ¼ men/hour at 2s. 6d. per man hour)	0·227
Water (400 galls/hr. at 1s. per 1,000 galls.)	0·014
Power (0·5d. per kwh.)	0·090
Depreciation and interest	0·340
Maintenance and supervision	0·092
Per therm	3·913

The Austempering and Isothermal Transformation of Steels

With Special Reference to the Production of Martensite

By F. C. Thompson, D.Met., M.Sc., and L. R. Stanton, Ph.D.
(*University of Manchester*).

Employing a sensitive recording dilatometer in conjunction with hardness measurements and microscopic examination the transformation of austerite at temperatures in the martensitic zone has been investigated the results of which have been published by authority of the Alloy Steels Research Committee. A summary of the work by the authors, together with their conclusions is abstracted and given in this article.*

THE researches described in this paper, which has extended over nearly three years, are very far from being complete, but in view of the importance of the subject at the present time, it may be worth while to place on record the results which have so far been obtained, even if some of them require more examination, and the ideas to which we are tending, even if some may later prove to be unsound. It has become very clear that, simple as the technical process may appear at first sight, it is, in fact, subject to certain disturbing factors; the difficulties of reproducing even one's own results, and still more those of other investigators, are often formidable.

Summary and Conclusions

(1) Believing that the fundamentals of an industrial process must be understood before it can be carried out with maximum efficiency, the authors have devoted the larger part of this paper to a consideration of the scientific background of the mechanism of the isothermal transformation process, and have allowed themselves considerable latitude in their speculations. If in a given sample of an isothermally transformed steel a fully martensitic structure can be retained, it is clearly possible to modify the conditions so as to give any softer steel that may be desired. It is, therefore, to the transformation of austenite to martensite to which the authors have devoted their main attention.

(2) For the purpose of studying this breakdown a quenching apparatus was designed capable of providing a definite cooling rate, which, judged by the uniformity of the structure or hardness of the product or by the rate of change of length of the sample, gives good reproducibility.

Along with this a dilatometer of considerable sensitivity was employed. It should be pointed out, however, that the change of length of the sample may not be exactly proportional to that of volume. This is a potential source of error in all such dilatometric work, but the authors' results have done nothing to throw doubt on the conclusion of Bain and Waring[49] that, with samples of constant size and shape, the proportionality in the changes of length and of volume is close.

(3) So far as comparison with the results of other workers goes, the main difference in the results obtained on these considerably bigger samples is in the length of the induction period, which is a far less pronounced feature of the transformations studied by the authors.

(4) When samples of very similar "ordinary" analyses, but obtained at different times, are examined, marked variations in the results are found. A possible explanation of this is to be found in the varying amounts or states of some undetermined element, possibly (probably?) oxygen. If this shifts the S-curve to the left, i.e., in the direction of increased reactivity, then, for a given rate of cooling, the normal curve will be cut at some temperature distinctly lower than that for the "abnormal" steel. In one case martensite may result, and in the other, troostite, and an explanation of "abnormality" is at once obtained. This is in complete agreement with Bain's view that, "an abnormal steel is one of the fast-reacting type," the increased speed of transformation being possibly due to alumina inclusions which act as nuclei. In a similar manner marked vertical displacement of the curve may occur.

(5) On the basis of Tammann's curve for the change of the velocity of crystallisation with temperature an explanation is offered for the shape of the S-curve itself. On exactly the same lines rather hypothetical reasons are adduced for the shape of the areas in which proeutectoid phases are precipitated from the austenite, and for the extra hump found in the curves for steels in which separate carbides are formed, e.g., chromium and molybdenum.

(6) Alongside these curves the microstructures which can be obtained are discussed. It is shown that in some steels there is very strong evidence to support the view that in a certain temperature range, say, 450–550° C., there is a labile shower of acicular crystals of ferrite. This hypothesis is in excellent agreement with the very rapid transformation which is found in the same temperature zone. Fig. 4, curve 5, and Fig. 12, curves 2 and 4, for instance, of the paper by Flinn, Cook and Fellows[8] show a velocity of change for a chromium-molybdenum steel which is much greater at about 700° F., the middle of the temperature interval in which acicular structures are obtained, than either above or below. That this precipitated acicular ferrite contains carbon in solid solution is shown by its behaviour on more prolonged soaking, and by the gradual change in the etching characteristics as the temperature of treatment falls. This retention of carbon is clearly a result of its diminished rate of diffusion into the surrounding austenite, a process which has been confirmed by X-ray examination. The gradual rate of the change of this ferritic structure through bainite to typical martensite is a metallographic feature worthy of note.

*Paper No. 16/1944 of the Alloy Steels Research Committee; Iron and Steel Institute, Nov., 1944, advance copy.

If some name is required for this ferrite supersaturated with carbon, might not Benedicks' term "ferronite" be revived? It is true that it was originally coined to denote the iron component of pearlite, but this in Benedicks' view was again an iron-carbon (carbide) solid solution.

(7) The possibility of the carbon change-point being depressed by stress, so that the austenite is rendered stable at distinctly lower temperatures than the normal Ar_1 point, is considered, but the effect is shown to be so small as to be without importance from the present point of view.

(8) The period of induction is discussed at length. After reviewing the various reasons for such an effect, it is believed that the cause is to be found in the gradual relaxation of the stresses set up as a result of the sudden cooling, or of the volume change at the surface due to the formation of a skin of martensite. Further, the marked parallelism between the curve for the commencement of the breakdown and that for its completion suggests that the former corresponds to the time at which the transformation becomes measurable, or, in in other words, that there is in reality no true period of induction, the change going on all the time, but at a rate so slow as to be initially undetectable.

(9) If the induction period is, as the authors suggest, a period of stress relaxation it might reasonably be expected that it should bear some relationship to the creep properties of the steel. That this is qualitatively so is quite clear from the general shift of the curves with change of composition.

Recorded below are some values of the creep limit given by Tapsell,[41] together with the times at the same temperature required to give the first detectable breakdown of the austenite. A temperature range around 500° C. has been chosen, i.e., that at which the transformation is generally most rapid. All the creep values given are for material which has received no special heat-treatment :—

Steel	Temp. °C.	Time for Commencement of Change, Secs	Creep Limit, Tons/sq.in.
C. 0·25%	500	<0·5	2·4– 4·2
C. 0·25%, Mn. 1·7%		0·9	5·0
C. 0·25%, Ni. 3·25%		0·8	4·7– 5·2
C. 0·17%, Ni. 5·2%	450	1·5	6·5– 7·6
Ni.–Cr.–Mo.		12·0	22·4–24·4

Although the compositions of the two series of steels are not the same, there can be little doubt about the general parallelism of the results. The dilatation curves obtained consist in their most general form, of five stages, which pass imperceptibly into each other. First, there is a rapid expansion due to the formation of the martensitic skin, which dies away and leads[2] to a stage of temporary equilibrium analogous to the induction period. This is succeeded[3] by a second expansion, initially exceedingly slow, but increasing in velocity until, over a limited range,[4] it gives a curve which coincides with that of a pseudo-first-order reaction, i.e., one in which the rate is proportional to the amount of unchanged austenite. The fifth and final portion consists of a curve indicating a diminished rate of change but which is still measurably greater than that which the first-order reaction would require. This part of the curve does not become asymptotic to the ordinate corresponding with the complete breakdown, but cuts it at a definite angle. The rates of change corresponding with these stages are shown in the accompanying figures.

How far nucleation effects exert an influence on the formation of martensite is a matter which is far from certain. A nucleation curve can be fitted well on to section 2 and the earlier portion of section 3. Further, since it is difficult to deal with the restrictions imposed as a result of the high viscosity of the material, a sort of "bottleneck" may be set up, as a result of which the rate of nucleation and subsequent growth will be materially decreased. A still better approximation to section 3 of the observed curve would thereby result. Even taking this into consideration, however, the authors are not disposed on the evidence available to believe that nucleation is a process which plays any considerable part in the formation of martensite, a process which they think bears a marked similarity to the production of mechanical twins.

The complication introduced by the existence of two forms of martensite has been considered. It is shown that there is some experimental justification for the belief that at "low" quenching temperatures tetragonal martensite may first be formed and then tempered almost at once to the cubic variety.

(11) The tempering curve of a martensitic steel, transformed isothermally, differs radically from that of oil- or water-quenched material. In the former there is little or no evidence of the contraction between 100° C. and 200° C. owing to the martensite inversion. The samples are, therefore, already (mainly) in the cubic state. Further, the hardness figures for a given steel are markedly different when the specimen is water-quenched, or isothermally transformed to give a completely martensitic structure, and then tempered at a temperature above that at which the solid solution has broken down. The hardness of the steel quenched in a molten metal bath, when subsequently retempered, is appreciably higher than that of the water-quenched material similarly treated. This can only mean that the martensite produced by the former treatment is more stable than that of the water-quenched steel, which is exactly what would be expected if it were in a condition of much lower internal stress.

(12) The martensite in the tetragonal condition etches very slowly, and shows light needles in a darker-etching background. That from steels which show no inversion change and which, therefore, are presumably already cubic, etches far more readily, and it is the needles, then, which are dark, the background being almost unattacked.

(13) Since the possibility of treating samples of some considerable size and yet retaining a fully martensitic structure was one of the aims of the more practical aspect of this work, the maximum size of bar which could be treated was investigated at length. The authors have succeeded in doing this in the case of a eutectoid steel in bars of up to 0·3 in. in dia., and for a 1·2% carbon steel, quenched above the cementite line, up to 0·45 in. in dia. These results are much in advance of anything hitherto recorded. It is clear that if a troostitic structure is adequate—e.g., for certain types of springs—austempering might be feasible up to even bigger dimensions. The nickel-chromium steel, as would be expected, remained fully martensitic at the largest size with which the authors could deal.

(14) The effect of grain size has been discussed in some detail, and it is shown that there are strong reasons for the view that, so far as the Ar′ point is concerned, it exerts a considerable effect, the steel reacting more and more rapidly as the grain size becomes smaller. The Ar″ change, however, is apparently unaffected, neither variations of quenching temperature nor of time at

that temperature having, in the authors' investigations, any effect on the subsequent transformation of the austenite.

(15) Earlier results which suggest that quenching in a metal bath shows little sign of the initial period of very slow fall of temperature so characteristic of normal quenching operations are confirmed. Rapid cooling sets in within a fraction of a second of immersion, and, as a result, the quenching is distinctly more effective than might at first sight be expected. Further, the authors' results have shown no measurable difference, other things being the same, when the composition of the bath, and hence its thermal properties, is altered.

It would be desirable to have proof that the precipitation of a pro-eutectoid phase at very high austempering temperatures has not sometimes occurred during the quenching itself. There is proof[42] that reactions can take place in the specimen prior to reaching the bath temperature, this being greatest in the case of quenchings in a medium at about 550° C. Recalescence may then take place during the cooling to an extent of nearly 50° C. The more rapid fall of temperature associated with quenchings in baths at lower temperature in which martensite can be retained do not, however, show any signs of such preliminary breakdown of the solid solution.

If the rate of cooling is not sufficiently rapid to suppress the Ar′ change entirely, it has been shown that the subsequent transformation in the bath is not materially affected by the presence of the troostite.

(16) Experiments on the effects of the pre-existing structure upon the results of isothermal transformation have indicated the rather surprising reactivity of samples which, *before this treatment*, were in the sorbitic condition. To a lesser degree the same sort of result was obtained from samples consisting of spheroidal pearlite. The effect for ordinary sorbite was checked by repeatedly treating the same (originally laminated) sample. The first curve, from the pearlitic steel, was appreciably different from the three succeeding ones, which just below the Ac_1 point would be sorbitic.

So far as the results on pearlite of varying degrees of fineness are concerned neither the dilatation curves, structures nor hardnesses showed any appreciable variation.

(17) It would appear, then, that, apart from changes of composition in the ordinary sense, the two factors which, more than any others, affect the results of isothermal treatment are, first and foremost, the degree of deoxidation, and secondly, the existence of a sorbitic structure in the material before treatment.

(18) It has been suggested that the breakdown of austenite may not be the same when quenching from a state of complete equilibrium as when quenching from a temperature range in which diffusion is proceeding.

(19) On the fundamentally important subject of the reasons for the difference of properties obtained from a normally quenched and an isothermally transformed steel, respectively, this work seems to have thrown some light. At temperatures above that of the Ar″ change there is, of course, little difficulty. The fact that the aggregate, troostite or sorbite, is formed directly from austenite without passing through the intensely stressed martensitic state will eliminate much of the danger of the formation of micro-fissures.

In those cases, however, where martensite is formed the difference may be reasonably ascribed to the production, in the metal bath, of the cubic form directly, or at any rate through the intermediary of tetragonal martensite of the most transitory existence. The absence (or, one ought rather to say, the low degree) of internal stress in martensite formed at the temperature of a molten metal bath is evidenced by its resistance to further tempering. As a result, although such martensite is originally distinctly softer than that formed by normal quenching, the tempered product may be distinctly harder (and, of course, tougher).

(20) In conclusion, the fact must again be stressed that this contribution to the subject has appeared before finality has been attained in a number of directions, even within the limited field of this stage of the authors' investigation. Infallibility is claimed neither for the results nor for the hypotheses here offered; in fact, the more the authors are in error, the more likely it is that this will be pointed out and knowledge of the subject thereby advanced.

If there is one point in connection with the more theoretical aspect of the work, which cries aloud for elucidation, it is the condition of the carbon and/or carbide in solution in γ-iron.

REFERENCES:

1 H. Brearley: "The Heat Treatment of Tool Steel," p. 100. London, 1916: Longmans, Green & Co.
2 P. Dejean: *Revue de Metallurgie, Memoires*, 1917, vol. 14, p. 641.
3 P. Chevenard: *Revue de Metallurgie, Memoires*, 1919, vol. 16, p. 17.
4 A. Portevin and M. Garvin: *Journal of the Iron and Steel Institute*, 1919, No. I., p. 469.
5 Dartrey, Lewis: *Journal of The Iron and Steel Institute*, 1929, No. I., p. 427.
6 E. S. Davenport and E. C. Bain: *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1930, vol. 90, *Iron and Steel Division*, p. 117.
7 L. R. Stanton: *Journal of The Iron and Steel Institute*, 1943, No. I., p. 95.P
8 R. A. Flinn, E. Cook and J. A. Fellows: *Transactions of the American Society for Metals*, 1943, vol. 31, p. 41.
9 E. S. Davenport: *Transactions of the American Society for Metals*, 1939, vol. 27, p. 837.
10 G. A. Roberts and R. F. Mehl: *Transactions of the American Society for Metals*, 1943, vol. 31, p. 613.
11 G. Tammann: "A Text Book of Metallography." New York, 1925: The Chemical Catalog Co., Inc.
12 N. P. Allen, L. B. Pfeil and W. T. Griffiths: Second Report of the Alloy Steels Research Committee, p. 369, *The Iron and Steel Institute*, 1939, *Special Report No.* 24.
13 A. F. Hallimond: *Journal of the Iron and Steel Institute*, 1922, No. I., p. 359.
14 J. O. Arnold and A. A. Read: *Journal of the Chemical Society*, 1894, vol. 65, p. 788.
15 J. O. Arnold and A. A. Read: *Journal of the Iron and Steel Institute*, 1910, No. I., p. 169.
16 J. O. Arnold and A. A. Read: *Proceedings of the Institution of Mechanical Engineers*, 1914, p. 223.
17 J. O. Arnold and A. A. Read: *Proceedings of the Institute of Mechanical Engineers*, 1915, p. 247.
18 J. O. Arnold and A. A. Read: *Journal of The Iron and Steel Institute*, 1911, No. I., p. 249.
19 J. O. Arnold and A. A. Read: *Journal of The Iron and Steel Institute*, 1912, No. I., p. 215.
20 J. O. Arnold and A. A. Read: *Proceedings of the Institution of Mechanical Engineers*, 1915, p. 269.
21 C. A. Edwards and A. Norbury: *Journal of The Iron and Steel Institute*, 1920, No. I., p. 447.
22 J. H. G. Monypenny: *Journal of The Iron and Steel Institute*, 1920, No. I., p. 493.
23 W. C. Roberts-Austen: *Proceedings of the Institution of Mechanical Engineers*, 1893, p. 102.
24 C. A. Edwards and H. C. H. Carpenter: *Journal of The Iron and Steel Institute*, 1914, No. I., p. 138.
25 F. C. Thompson and W. E. W. Millington: *Journal of The Iron and Steel Institute*, 1924, No. I., p. 67.
26 C. Benedicks: *Journal of The Iron and Steel Institute*, 1908, No. II., p. 158.
27 E. C. Bain: *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1932, vol. 100, *Iron and Steel Division*, p. 13.
28 J. B. Austin and R. R. Rickett: *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1939, vol. 135, *Iron and Steel Division*, p. 396.
29 R. Mehl: *Transactions of the American Society for Metals*, 1941, vol. 29, p. 813.
30 J. H. Andrew, J. E. Rippon, C. P. Miller and A. Wragg: *Journal of The Iron and Steel Institute*, 1920, No. I., p. 527.
31 B. D. Enlund: *Journal of The Iron and Steel Institute*, 1925, No. I., p. 305.
32 L. Teager: *Zeitschrift des deutscher Ingenieure*, 1927, vol. 71, p. 891.
33 J. H. Whiteley: *Journal of The Iron and Steel Institute*, 1925, No. I., p. 315.
34 K. Honda and Z. Nishiyama: *Science Reports of the Tôhoku Imperial University*, 1932, Series 1, vol. 21, p. 299.
35 E. E. Legge: *Metals and Alloys*, 1939, vol. 10, Aug., p. 228.
36 A. B. Greninger and A. B. Troiano: *Transactions of the American Society for Metals*, 1940, vol. 28, p. 537.
37 H. Esserand H. Maiert: *Archiv. für das Eisenhüttenwesen*, 1933, vol. 7, p. 319.
38 W. T. Griffiths, L. B. Pfeil and N. P. Allen: Second Report of the Alloy Steels Research Committee, p. 343, *The Iron and Steel Institute*, 1939, *Special Report No.* 24.
39 H. J. French: *Transactions of the American Society for Steel Treating*, 1930, vol. 17, p. 646.
40 E. C. Bain and W. S. N. Waring: *Transactions of the American Society for Steel Treating*, 1929, vol. 15, p. 69.
41 H. J. Tapsell: "Creep of Metals." Oxford, 1931: University Press.
42 M. Gensamer, E. B. Pearsall, W. S. Pellini and J. R. Low: *Transactions of the American Society for Metals*, 1942, vol. 30, p. 983.

The Yielding Phenomenon of Metals

Influence of Speed and Loading Conditions*

Part 1

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The yielding phenomenon of metals, of importance in applied mechanics as well as in metallurgy, is not yet sufficiently understood. Besides a theoretical consideration, the various factors which have a pronounced influence on the yielding of metals such as the kind of testing machine with its load-indicating device, as well as the rate of plastic deformation of the specimen, have been investigated. In order to obtain additional results about the loading conditions of the specimen, a new direct loading machine with a special recorder was designed, and the stress-strain diagrams of this machine were compared to those of the rigid straining machine. Furthermore, the transmission of the loads from the machine into the test specimen without harmful secondary effects was studied by means of three types of newly developed universal joints which allow loading the specimen axially.

In order to understand the whole stress-strain diagram, an automatic time chronograph was designed.

Furthermore, the characteristics of the two types of machine, the rigid straining machine and the direct loading machine, were compared to each other during the static loading tests, as well as during the dynamic tests with the machine in normal operation. During these tests an artificial yielding effect was obtained by a relative displacement of the loading faces of the machines. Stress-strain diagrams were recorded under different loading conditions; diagrams showing a most characteristic difference between these two types of machines were obtained.

By means of a special device based on sliding friction between three plates screwed together, the dynamic behaviour during yielding of metals in both types of testing machines was analysed and interesting diagrams were recorded. The rigidity of the straining machine could be gradually decreased by inserting elastically stressed elements between the grips and the frame of the machine. In five different steps the characteristics of the rigid straining machine were gradually made nearly equal to those of the direct loading machine.

Comparative tests with usual extensometers measuring in different places the relative movements of the grips and the loading faces of the machine gave valuable indications about the reliability of these instruments.

The upper and lower yield-points of mild steel were studied in function of the speed between about 400 lb. and 20,000 lb. per min. These tests show that the lower yield-point is much more affected by high deformation speed than the upper yield-point.

Time-controlled stress-strain diagrams show in all loading phases important variations of the loading speed in the rigid straining machine and the straining speed in the direct loading machine. The difference between the two types of machines becomes especially effective by comparing the stress-strain diagram of duralumin test specimens tested shortly after quenching and showing a very characteristic yielding effect.

A—INTRODUCTION.

THE problem of yielding of materials, especially the phenomenon of the upper and lower yield-points of steel, has been the subject of a great number of investigations. It is a well-known fact that the yielding phenomenon is of great importance as well as in applied mechanics, as in metallurgy. Since the end of last century a considerable amount of research work has been made to clarify this problem. Nevertheless, it would be very difficult to give at present a clear and exact explanation of this subject; based on the existing publications, it is not yet possible to explain this phenomenon. It may be said that this problem is one of the most difficult in the field of testing materials. The more this phenomenon is investigated, the more it becomes obvious that the many factors involved make a complete solution under the present state of knowledge very difficult.

By previous investigations we have learned that the shape (length and diameter) as well as the chemical composition of the test specimens, cannot be neglected in this investigation. Furthermore, we know that the clamping devices between the test-piece and the cross-head of the machine, and especially the testing machine itself, are of prime importance in this respect. We know also that the speed of stretching and the rate of loading during the first period of the test have a pronounced influence on the upper and the lower yield-points of steels. Furthermore, the speed of stretching in the yielding period varies in very great limits, so that it may be also of interest to study the influence of the speed of straining during this period in relation to the loading system employed for this kind of investigation. As amongst these various factors the kind of testing machine and its load-indicating device, as well as the rate of plastic deformation, seem to have the greatest influence on the yielding of steel, these subjects were chosen as the main objects for this investigation.

(a) The testing machines and the stress-strain recording devices

Most of the tensile tests are made to-day by clamping the test specimen by means of special grips in a rigid

* This investigation was made possible by a grant of the Carnegie Corporation of New York. The author expresses here his very best thanks to the Carnegie Corporation of New York for the generous support of this work.

machine which imposes to the specimen a certain deformation. The resistance which the specimen opposes to the machine during its deformation is measured by special load-measuring devices which are generally inserted between the frame of the machine and the test specimen itself. These machines may be called rigid-straining machines.

Another type of machine is the direct loading machine. The simplest device of this kind consists in fixing the specimen at one end and suspending at the other a weight which can be increased gradually. For instance, by water flowing in a reservoir attached to the specimen, the direct load type machine is easily obtained.[1] Of the same principle, but somewhat modified, is the machine with a lever inserted between the test specimen and a weight which can be displaced laterally, as shown by Davis.[2] This type of machine is named direct loading machine. For this type, the test specimen is not submitted to a certain forced deformation by measuring the corresponding load, but the load is increased, and the corresponding free deformation of the specimen is measured.

In order to obtain the relation which exists between the load and the deformation of the specimen during testing, most of the usual testing machines are fitted with special devices to draw a record in the form of a stress-strain diagram of the specimen under load. The stress is generally recorded as ordinate and the deformation as abscissa. The recording of the main factors of a tensile test in a stress-strain diagram does not seem to present any particular difficulty. However, if we want to receive an exact picture of what happens in the test specimen itself without any secondary effect of the elements of the testing device in which the test-piece is loaded or strained, the question becomes more complicated. This is what we want to know, and it is necessary to separate as far as possible the influence of the testing device itself on the results of the test-piece during yielding. Attempts in this direction were made a few years ago by Fry ;[3] he investigated the mechanical modulus of the testing machine, which, as may be easily understood, varies greatly with the kind of testing machine (hydraulic, pneumatic or mechanical) and the type of load-indicating device.

(b) Stress-strain diagram

(1) *Direct Loading Machine.*—The theoretical stress-strain diagram recorded on a direct loading machine may be represented as shown in Fig. 1, by a straight slightly inclined vertical line O–A, which represents the elastic deformation of the specimen and an horizontal line A–B, representing the plastic deformation of mild steel, for instance, at its yield-point. During the plastic deformation of the specimen the lever arm and the weight of the direct loading machine drop a short way down ; but being around the horizontal position, no remarkable change in the load or the ratio of the lever arm takes place, so that the load remains practically the same in the yielding period between A and B of the diagram. The yielding is characterised in this case by an horizontal line A-B in the stress-strain diagram recorded by the machine. After the total yielding A–B, which takes place in a fairly short time, as will be shown later, the test specimen elongates further with the growing load between B–C, increasing faster than during the elastic period O–A of the test specimen. After having reached the maximum load in C which the test-piece can support, the test-bar reduces locally its cross-section (neckdown) ; however, without any dropping of the maximum load applied, and this during the total local plastic flow between C and D. As will be shown later, beginning from the maximum load in C, the speed of deformation increases gradually to the point D, where final rupture of the specimen takes place.

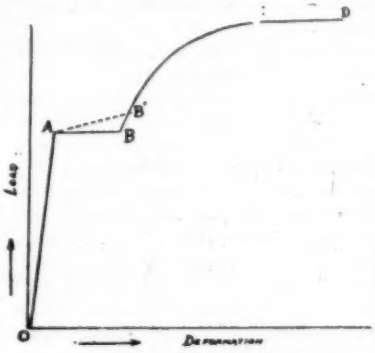


Fig. 1

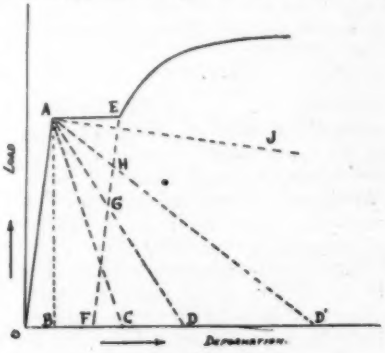


Fig. 2

(2) *Rigid Straining Machine.*—The loading process of this type of machine is quite different from that of the direct loading machine. Consequently, the records of the stress and strain in the diagram are also completely different. Considering a hydraulic rigid straining machine with loading cylinder and a hydraulic loading control device (hydraulic capsule), a principle on which most of the modern testing machines are based, we can see that the shape of the stress-strain diagram changes considerably for the same test specimen. By loading the test specimen elastically up to the yield-point A, a straight line O–A is shown in Fig. 2, which represents its elastic stress-deformation record, and O–B is the elastic deformation of the specimen. However, in order to put the specimen under load, an additional elastic deformation of the hydraulic machine itself takes place, which may be characterised by the distance B–C, B–D, or B–D′ on the abscissa of Fig. 2. These distances depend on the so-called modulus of the testing machine. The loading of the machine is accompanied by the elastic deformation of its whole mechanism, which can be characterised by the straight line C–A, D–A, or D′–A (Fig. 2), depending on the more or less elastic deformation of the different parts of the hydraulic machine under load, as, for instance, the cylinder, the plunger, the oil under pressure, and the other elements of the machine through which the forces are conducted to put the specimen under load. According to the degree of rigidity of the machine used, these elastic deformations may vary between very great limits, where the vertical line A–B represents a machine with a maximum rigidity, that means an elastic deformation under load A equal to zero. On the other hand, the extremely elastic or soft-spring machine would be represented by a line A–I approaching the horizontal line A–E of the direct loading machine. This could be obtained, for instance, with a pneumatic machine loaded by means

1 (a) "Research on Yield Limits and the Tensile Strength of mild steel and other metals," by G. Welter, METALLURGIA, p. 89, January, 1936.
(b) "The upper and lower Yield points and the breaking Strain," by G. Welter, METALLURGIA, vol. 13, p. 183, April, 1936.
2 "The Effect of the Speed of Stretching and the Rate of loading on the Yielding of mild steel," by E. A. Davis, *Journal of Applied Mechanics*, p. A-137, December, 1938.
3 "Speed in Tension and its influence on Yield point Values," by Lawford H. Fry, *Proceedings A.S.T.M.*, vol. 40, p. 625, 1940.

of a cylinder and a piston actioned by compressed air instead of oil pressure.

If the test specimen, after an elastic deformation O–A, elongates at the point A plastically by yielding, as for the first case, on a distance A–E, for instance (Fig. 2), then a quite different distribution of the stresses and strains takes place between the machine and

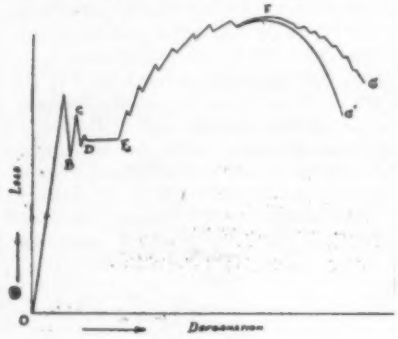


Fig. 3

the test-piece. Such a machine gives a diagram completely different to that of the direct loading machine. If the test specimen flows plastically after having passed the elastic limit, the elastically stressed machine under load is released by the elongation of the specimen and the load drops according to the rigidity of the machine, either along A–C or A–D, for instance (more precisely in alternative steps partly along A–B and A–G or A–H) down to the point G or H, where these lines encounter the line E–F. It is along this line that the test specimen, on its own account, shortens, due to the drop of

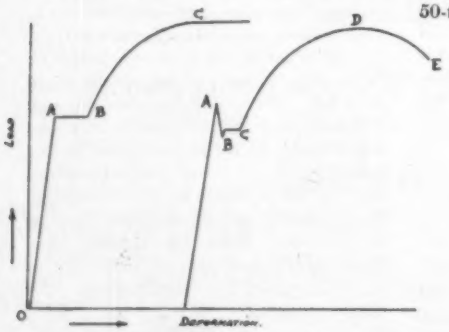


Fig. 4

the load and the diminishing of the elastic strain in the machine. If the machine is very stiff this displacement of the equilibrium of the forces in the test-piece and in the machine may take place several consecutive times, accord- A–B–C–D (Fig. 3) until the elongation of the test specimen is in equilibrium with the load of the machine in D–E. After that deformation, the yielding of the steel is exhausted and the load increases again regularly with the plastic flow of the material, until the maximum load in F is reached. This plastic flow takes place in small steps up to point F. After this point the local deformation of the test specimen interferes again with the elastic straining of the testing machine, showing a dropping of the load, till the test-piece breaks in G or G′. This falling off of the load also takes place in quite imperceptible steps F–G, as shown in Fig. 3, which, due to the mass of the machine and the rapidity of the flow of the material, are not recorded in the diagram. If the rigidity or stiffness of the machine is very high, this drop of the load may be very pronounced, as this can be observed frequently in commonly used testing machines (F–G′).

According to this theoretical deduction of the stress-strain diagram, in relation to the testing machine, as also studied by Spath,[4] it was pointed out by the author that the shape of the diagram is greatly influenced by the machine, and it could be shown that direct loading machines indicate diagrams as represented in Fig. 4, while the rigid straining machines show always the peculiar drop of the load at the yield-point as well as at the breaking load of the specimen.[5] Also, a few types of usual rigid machines could be changed by springs or gas cylinders in the loading circuit of the machine in a fundamental manner, as shown by previous work of the author,[6] see Fig. 5 for 5-ton (A), 20-ton (B), and 50-ton machines (C)

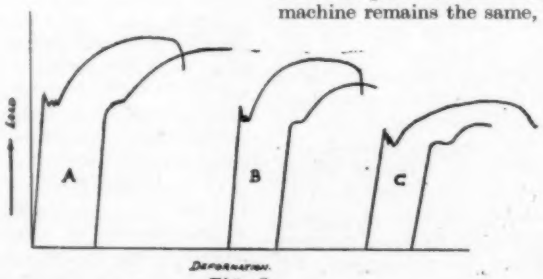


Fig. 5

4 "Physik der Mechanischen Werkstoffprufung," by W. Spaeth, J. Springer, Berlin, 1938.

5 (a) "The Stress-Strain Diagram and the Rate of deformation by tension of plastic materials in relation to loading conditions," by G. Welter and S. Gockowski, *Institute of Metallurgy and Metallography, Warszawa*, p. 95, No. 3, 1936.

(b) "Some Fundamental Factors Regarding the Stress-Strain Diagram of mild Steel," by G. Welter and S. Gochowski, METALLURGIA, vol. 18, p. 99, July, 1938.

6 "Influence of the Resiliency of the test-machine and of the loading speed upon the Determination of the Yield point for mild steel," by G. Welter and S. Gockowski, METALLURGIA, p. 143, August, 1939.

(c) Rate of loading and speed of stretching

It is a well-known fact that, presumably due to internal friction, the tensile strength of most materials rises if the rate of loading increases. As the yielding of steel is a phenomenon which

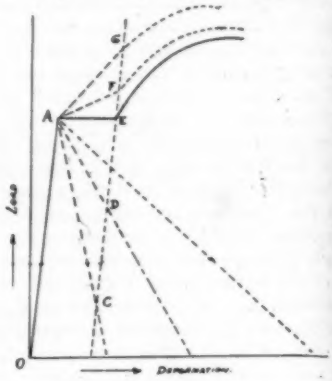


Fig. 6

generally takes place rapidly while the load falls suddenly down from an upper limit to a lower one, it is obvious that the rate of loading must have an additional marked effect on the yielding phenomenon and this especially for rigid straining machines.

(1) *Rigid Straining Machines.*—If, for instance, the rate of loading is small compared to the speed of yielding, then the load drops down in the rigid machine along the elastic line A–C of the machine, as shown in Fig. 6. For instance, if the rate of loading is increased, the loading faces of the machine move faster and consequently the speed of stretching is higher, but not as high as the yielding process itself and provided the elasticity of the machine remains the same, then, in a given time unit, an additional elastic elongation occurs and the load does not drop to C, but only to D, for instance. Due to the higher rate of loading, the machine seems to have in this case a higher grade of springiness according to A–D; it seems to be softer—that is, more elastic. If this rate is increased, the rigid machine

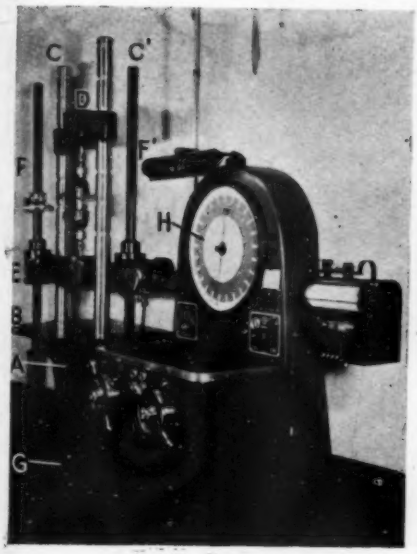


Fig. 7

may theoretically give results in the stress-strain diagram similar even to a direct loading machine, as, for instance, a diagram according to C–A–E (Fig. 6), and yet higher loading rates may record not only no drop of the load, but from point A even an increasing load during yielding may take place, as represented in A–F or A–G in Fig. 6. This is due to the fact that the loading grips move faster than the material is able to yield. However, as will be seen later, for this case unusual high rates of loading are necessary, and the conditions will approach the dynamic. It does not seem likely that the rate of loading of the ordinary rigid testing machine can be increased in such a way that the disappearance of the lower yield-point takes place in the record. For instance, Siebel and Pomp[7] found during compression tests that by increasing the speed of straining up to 1·25%, the recorded diagrams regarding the dropping of the load from the upper to the lower yield-point became flatter; that is, changes from A–C to A–D (Fig. 6) took place for a test lasting only a few seconds, without, however, disappearance of the lower yield-point. For a specimen of mild steel of 1 in. length and a total deformation at the yield-point of about 2 to 4%, the tests would last only a few seconds. It may be reasonably supposed that much faster tests are not possible with the existing static testing machines. So it will not be probable that the automatic record of the stress and strain will be reliable under such relatively high testing speeds.

7 E. Siebel and A. Pomp, *Mitt. Kais. Wilh. Inst. Eisenforschung, Düsseldorf*, p. 63, Bd. 10, 1928.

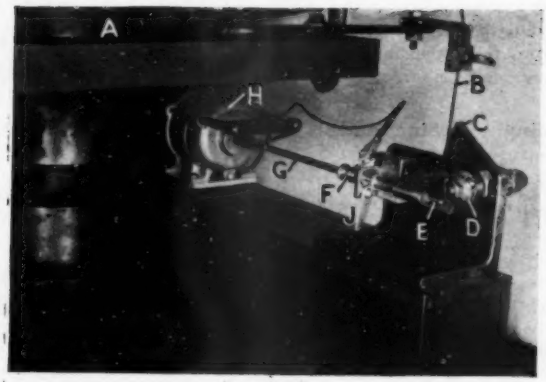


Fig. 8

(2) *Direct Loading Machines.*— With the direct loading machine the rate of loading has hardly no effect on the stress-strain record. The elongation of the test-piece during yielding takes place under the same conditions irrespective of the rate of loading. Only if in the extreme high-speed test the rate of loading becomes excessive can it also be imagined that the gripping devices of the machine separate faster than the test-piece can flow; in this case there will be a somewhat increasing load during yielding, as, for instance, indicated in A–B′, Fig. 1.

B—TESTING MACHINES AND DEVICES USED

As already shown, the testing machines have a marked influence on the yielding of materials. Especially, the shape of the stress-strain diagram can be changed appreciably by using different types of machines. Therefore, no research, no reliable results, no clear understanding of the yielding with the characteristic drop of the load will be possible, as long as the fundamental question treated above has not found a satisfactory solution. No further progress about this puzzling problem will be possible if a clear and reliable answer of this point is not available. It results from these considerations that a research dealing mainly with this subject seems to be of some interest for the future of the testing technique of metals.

In view of this fact, two extremely different types of machines were used for this investigation. On one hand, the usual rigid straining machine was used as a type of a quite rigid or hard machine, which, however, can be changed by varying the load-measuring device with different kinds of springs. On the other hand, a direct loading machine of the simple lever-weight type, representing the extreme opposite of the rigid machine, was especially developed for this kind of investigation. Here is a brief description of these two testing machines.

(a) Rigid straining machine and recorder equipment

This machine is of the usual type as currently used in most testing laboratories. It is the hydraulic Baldwin Southwark Tate Emery Universal testing machine, of a capacity of 60,000 lb., with three loading ranges of 2,400 lb., 12,000 lb., and 60,000 lb., as represented in Fig. 7. The ram of the straining cylinder A is forced upward by the oil pressure, and it lifts the table B, which carries by means of the steel columns C–C′ the cross-piece D at the top of the machine. The middle cross-piece E is connected by means of the columns F–F′ with the weighing system G at the bottom of the machine where the steel cylinder piston is transmitting the pressure of the machine to the load-indicator system H. The recording equipment of this machine is automatic. Either the displacement of the cross-head of the machine is recorded in function of the loads by means of several pulleys fixed at the cross-heads of the machine and a cord connected with the recorder drum or by an electrical load-deformation recorder, developed by the author and based on the principle of the Peters' compressometer. The translational movement of the cross-head A of the machine is communicated through a flexible thin steel strip B (Fig. 8) to a segment C, and is reduced by the segment D in the relation of 1-to-5. The horizontal cylindrical bolt E, with a spiral spring and a silvered top, conducts a micro-screw F, coupled by means of the axis G to the Selsyn motor H, communicating the vertical movement of the cross-head to the recorder. A lever I which frees the contact between the horizontal cylinder and the micrometric screw F, protects this screw from accidental damage when the

device is not in use or is being adjusted. This instrument as well as the electrical Peters-Templin extensometer were used for this investigation.

(b) Direct loading machine and its automatic stress-strain recorder

As this research was projected to study the influence of loading conditions on the test specimens, it was necessary to change over from the existing conditions of the usual rigid testing machine to a direct loading of the test specimen. The rigidity of the usual testing machine is so great that at the yield-point very little additional deformation often causes a sudden drop of load to values far beneath the maximum loads applied. To reproduce, however, loading conditions as they are encountered in most of the usual constructions where the load does not drop if the material yields, it was necessary to develop a completely new testing machine for this investigation, because such a machine is not available on the market. This machine, called a "direct loading machine," was designed and constructed in the machine-shop of the Ecole Polytechnique, adjusted, controlled and tested as to its operating qualities in the mechanical laboratory. An automatic load-deformation recorder was also developed. This machine, with a maximum load of 2,000 lb., gives very satisfactory operating results and permits the study of the yielding process of mild steel from another point of view, showing quite different load-deformation diagrams as compared to those recorded by the usual rigid tensile testing machines.†

The machine as shown in Figs. 9 to 12 is of the lever type, with a ratio of 1 to 12, and has a vertical 10 in. U-beam A of about 6½ ft. high as main support, through which the flow of loading forces takes place. This beam is screwed on the base frame B by means of cross-bars and plates. The additional upper structure C supports the brake D of the machine. By attaching a weight E composed of four discs (about 177 lb.) at the end of the long lever arm F, a maximum load of 2,000 lb. can be easily attained with this machine. The lever rotates on ball-bearings G in the head of the machine and the smaller lever H exerting the load on the test specimen is ended in a segment I with the axis of the lever as centre. On this segment is attached a hard-rolled blue-tempered double steel strip K of 0·0055 in. thickness, and $1\frac{3}{16}$ in. width. This strip is wound around the cylinder L, and both ends are attached to the upper gripping device M of the machine. This gripping device is divided along its longitudinal axis into two parts screwed together and supported at the upper end by means of a slotted transverse steel piece N, the steel strip being wound around them. On the other side of this device is attached by a nut the bolt O supporting the proper gripping device for the test-piece in form of a universal joint P. The test-piece Q is screwed on both sides in similar universal joints P–P', avoiding the least eccentricity in the loaded specimen. The lower universal

† This machine was projected, constructed, calibrated and tested as to its operating qualities with the valuable assistance of R. Auger, senior student, to whom the author expresses here his best thanks.

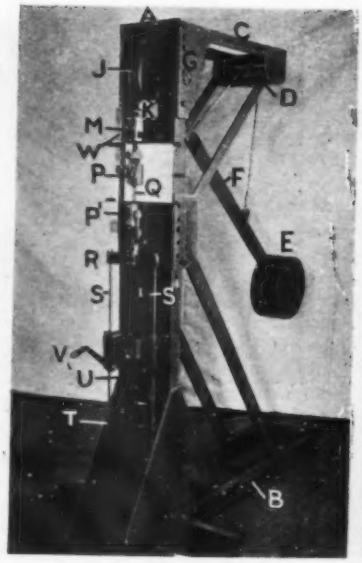


Fig. 9

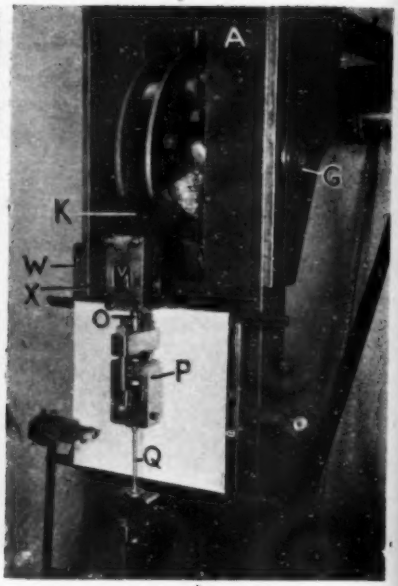


Fig. 11

Fig. 10

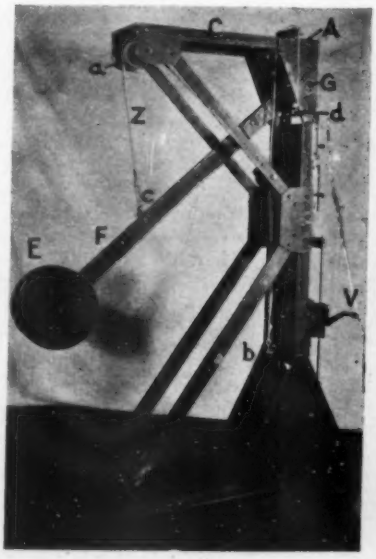


Fig. 12

joint is attached to a cross-beam R, which by means of two vertical bolts S–S′ transmits the load to a second beam T. By a jack U, put into movement by a crank V, the test-piece is gradually loaded. During loading the test specimen together with the gripping devices moves downward along a calibrated scale W fixed on the frame of the machine. The hand X indicates on the scale the applied load in pounds. The loads given by the machine at different positions of the lever were calculated and verified by an elastic calibration device. A Morehouse proving ring A of a capacity of 2,000 lb., as shown in Fig. 13, was used. The ring, constructed for compression

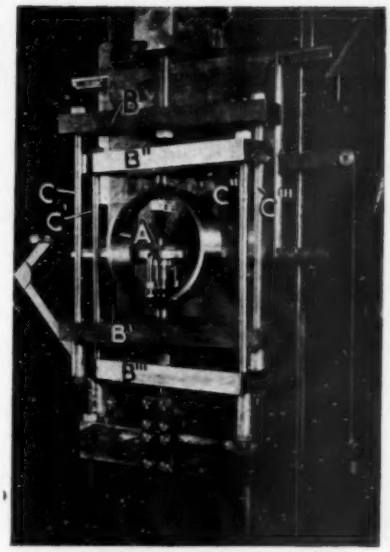


Fig. 13

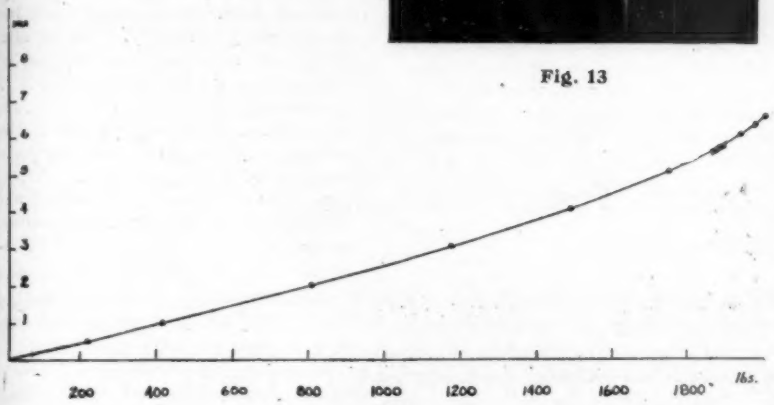


Fig. 14

loads only, was fixed in the machine by means of four transverse bars B–B′, B″–B‴ and four rods C–C′–C″–C‴ changing the tensile forces of the machine into compression forces acting between the middle transverse beams. In Table I and Fig. 14 are reproduced the measured and calibrated values of the loads in function of the displacement of the upper cross-head.

TABLE I.

Displacement of upper cross head inch	Division of micrometer	Calibration factor	Load lb.
1·000	100	4·015	401
2·000	200	3·993	799
3·000	292	3·974	1160
4·000	378	3·955	1495
5·000	441	3·942	1738
6·000	493	3·929	1937

The scale as fixed on the machine frame is shown in Fig. 15.

An automatic brake, as represented in Figs. 9 to 12, is provided to operate the machine with security. If the machine is in operation and the lever arm F goes upward, the cotton rope Z wound about two times around the small cylinder *a* is, by a counter-weight *b* of about 23 lb., so regulated that the rope or the counter-weight are without influence on the lever F. The rope in point *c* follows regularly the movement of the lever arm by the equilibrating weight *b*, which is just sufficient to balance the friction between the rope and the cylinder. However, if the test specimen breaks and no force counterbalances the upper cross-head of the machine, the falling of the main lever with the big weight is stopped instantly by the rope and the counter-weight exerting a friction high enough to keep the main lever in its attained upper position. By lifting the small counter-weight *b* by

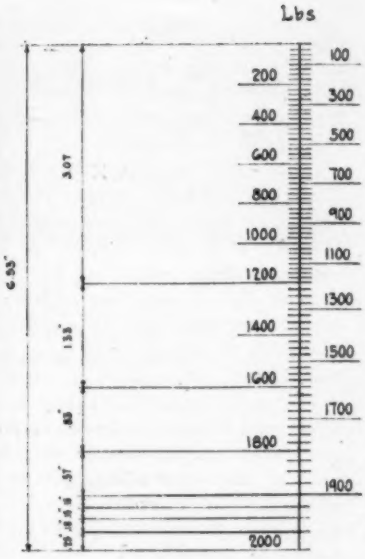
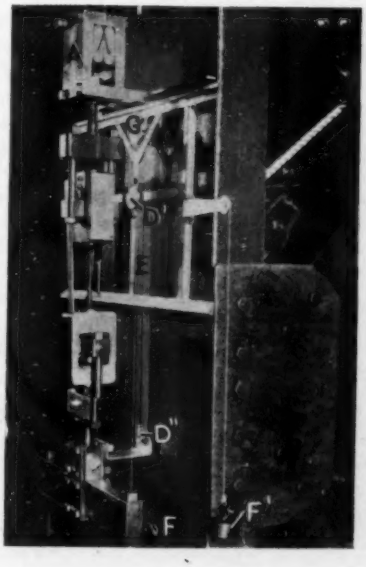


Fig. 15

means of a handle *d* the lever will be lowered securely and without any difficulty into its initial position.

An automatic stress-strain recorder as shown in Fig. 16 was also provided. On the upper cross-head A of the machine a rigid frame B is fixed, and on this frame slides on rollers and in two rails C–C′ a duralumin sheet on which the diagram paper is fixed. By a system of rollers D–D′ attached at this frame and the lower cross-head D″–D‴ of the machine, as well as a

Fig. 16



small string E passing on these rollers and counter-weights F–F′, the relative movement between the upper and lower cross-head—that is, the elongation of the test specimen—is recorded with a magnification of ×7. A pencil A attached rigidly and directly on the frame B of the machine according the close-up view of this part of the machine, represented in Fig. 17, touches slightly under the pressure of a very light spiral spring the paper on the table C, recording in this way the desired stress-strain diagram D during the downward movement of the upper cross-head of the machine. With rising loads the stresses are recorded, and the horizontal sliding movement of the table registers the strain of the test-piece. By these two movements, occurring simultaneously, the stress-strain diagram is recorded during the test on the paper.

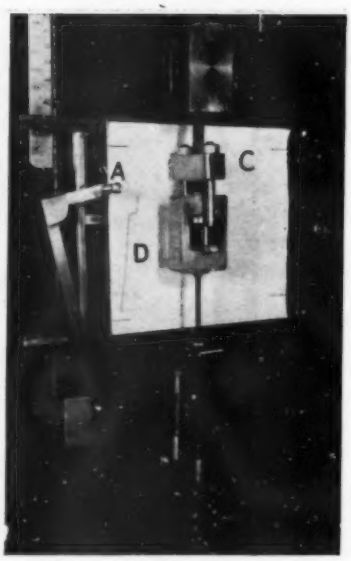


Fig. 17

The Salt Spray Test

By V. M. Darsey

THE salt spray test is a method of producing accelerated corrosion of articles placed in a finely divided dense wet fog produced and maintained by atomising a 20% solution of sodium chloride with air inside a cabinet at 92° to 97° F. Lack of adequate methods for measuring and maintaining a uniform concentration of salt fog inside the cabinet during operation is primarily responsible for most irregular salt spray test results. Recognised methods for calibrating the fog inside a salt spray chamber do not distinguish between so-called wet or dry fog, which are recognised to have different corrosion rates, nor do they distinguish between salt fog and fog resulting from the atomisation of water free from salt. To promote more uniform test results, research work has been carried out on a quantitative method of calibrating the salt fog inside the cabinet.

It was reasoned that the humidity inside the cabinet influenced the wetting of specimens and their ultimate corrosion, and before proceeding to determine the humidity in a salt spray cabinet, the humidity resulting from various concentrations of sodium chloride at equilibrium were computed from published vapour pressure data. It was found that at equilibrium the atomising of 20% salt solution results in a relative humidity of 84% inside a test cabinet. If it is determined that the relative humidity is less than 84% the salt particles of the fog will "give up" moisture to the air and thus tend to become a dry salt fog, while if the relative humidity is greater than 84% the salt particles of the fog tend to "take on" moisture from the air inside the cabinet.

To study the relationship between humidity inside a large spray cabinet (433 cu. ft.) and the concentration of the salt fog particles, measurements of humidity and fog solution concentration were made by atomising different concentrations of sodium chloride and ordinary water under normal conditions of salt spray operation. From the experiments it was found that the relative humidity in a salt spray cabinet was directly related to the sodium chloride content of the fog, and good agreement was obtained from salt concentration measurement of fog solution collected and humidity measurement by wet- and dry-bulb thermometers. Since the method of collecting a solution of fog and determining its salt concentration was more convenient than humidity measurement, an atomisation procedure is suggested for calibrating the salt fog inside a salt spray cabinet.

The fog solution collector in addition to providing a quantitative method of measuring the amount and concentration of fog in a salt spray chamber has proved a reliable indicator of operating conditions. When the average volume in millimetres of fog solution collected each 24 hours has been established from daily operating experience, the collection of any volume substantially different from this average indicates an operating difficulty. It is also recognised that the concentration of salt in the fog solution collected is of greater significance than the amount of solution collected, provided the amount is sufficient to ensure adequate wetting of test specimens. When specimens are wet and maintained wet during testing, additional fog solution is not necessary nor believed to influence the rate of corrosion.

Other important factors in salt spray testing that should be given consideration are that the salt should should be sodium chloride containing on the dry basis not more than 0·1% of sodium iodide or more than 0·2% of total impurities and that it should be prepared by dissolving 20 ± 2 parts of salt in 80 parts by weight of distilled water. The pH of solution should be maintained from 6·5 to 7·2 and the specific gravity from 1·126 to 1·157 at a temperature between 92° and 97° F., and should be so maintained during the test. The temperature of the interior of the salt fog chamber should also be maintained at 92° to 97° F., and under no conditions should the use of a heater in the salt solution be permissible to obtain the necessary temperature inside the cabinet. The compressed air supplied to the atomisers should be freed of all impurities such as oil or dirt and should have a relative humidity of not less than 85%. The fog, which should circulate freely around all the test specimens, as uniformly as possible, should be baffled prior to coming in contact with them, in order that it should not impinge directly on the specimens after atomisation.

From *Amer. Soc. for Testing Material Bulletin.* 1944. No. 128, pp. 31–34.

MICROCHEMISTRY
APPARATUS · METALLURGICAL APPLICATIONS · TECHNIQUE

READING, recently, an article on " The Electromagnetic Spectrum as an Analytical Tool," two points were once more brought home strongly to us. In the first place, the field of microchemistry is very largely the field of analytical chemistry, so that in general the competent analyst must be a competent microchemist. Where the electromagnetic spectrum is applied to analysis the methods are so often essentially microchemical that it is not always easy, on the spur of the moment, to think of an exception to this. Analytical problems may nowadays be solved by applications of infra-red, visible or ultra-violet spectography, both emission and absorption. In the visible region we have, in addition, the use of the microscope itself. Colorimetry and photometry, whether visual, photo-electric or photographic, are all instrumental methods which belong to this section of the field. If we pass to higher frequencies, X-ray analysis and electron diffraction, together with the electron microscope, are tools which at least penetrate largely into the province of the microchemist. The other point, a corollary of the first, is that it would be a bold discriminator who would attempt to distinguish clearly between instrumental methods of analysis in general and microchemical methods. Instrumental methods are usually justified by their speed. But in addition they are usually also to be preferred to classical methods since they permit of application to amounts which would have been ignored by the classical analyst. The microchemist nowadays rightly regards all instrumental methods of analysis as capable of serving his purpose; and in many cases he is not unjustified in looking on certain of them as his own special methods.

The Detection and Determination of Small Quantities of Mercury

By F. T. Beaumont, B.Sc.

A brief survey of recently developed methods for the detection and determination of small quantities of mercury, from fractions of a microgramme up to several milligrammes, is presented; These methods are of great interest and value, because of the wide distribution of mercury and because they include the solutions to some of the difficult problems of microchemistry.

METALLIC mercury and many of its compounds are readily volatilised, and this property may be both an advantage and a drawback when the detection or estimation of the element is in question. In some cases, the volatility can be used to effect a separation from other elements and their compounds.

The Detection of Small Quantities of Mercury

Amalgamation Tests.—F. Cucuel,[1] in a review of methods for the detection and estimation of mercury up to 1933, quotes the deposition of mercury on gold and on copper foil, and the co-precipitation of mercury and copper on a clean iron wire. The means of detecting the mercury after such deposition include the displacement of gold, silver and platinum from their salts by contact with mercury vapour, or distillation of the mercury on to a cold gold surface and observation of the change in colour due to the formation of an amalgam, or distillation into a narrow capillary tube followed by observation of the mercury droplets with a lens. The last procedure can be made much more sensitive by exposing the droplets to the action of iodine vapour, whereby red crystals of mercuric iodide are formed.

Test Depending on the Activation of Aluminium.—The earlier methods of carrying out this test[1] depended on the observation of the characteristic deposit of aluminium oxide caused by contact of clean aluminium metal with a moistened salt of mercury. Even when the activation is enhanced by electrolysis of a mercury salt solution, the test is not nearly so sensitive as the modification due to F. Feigl and collaborators,[2] who use the formation of the aluminium lake of alizarin to detect very small amounts of aluminium oxide. Feigl deposits the mercury electrolytically on aluminium foil, using a depolariser and ensuring that the solution is a good conductor by adding sodium sulphate. After careful washing, the surface of the foil is treated with an acetic acid solution of alizarin and, on washing away this solution, red spots of the

1 *Mikrochem.*, 1933, **13**, 321.
2 " Spot Tests," 2nd English translation of 3rd German edition.

lake are seen on the foil when mercury is present in the original electrolyte. The test detects 0·0001 μg. of mercury at a concentration of 1 in 5×10^8.

Tests depending on the Microscopic Identification of Crystals.—The precipitation of mercury cobalt thiocyanate, $Hg[Co(CNS)_4]$, formed by the action of cobalt nitrate and ammonium thiocyanate, has long been used[1] as a sensitive test for mercury, and will detect 0·04 μg. at a concentration of 1 in 14,000.

I. M. Korenmann[3] precipitates zinc mercuric thiocyanate in a similar manner, and identifies the crystals under the microscope. The sensitivity of the test is increased by the addition of a small amount of ferric salt, which gives colour to the precipitate.

A. Martini[4] has studied both zinc and cobalt thiocyanate complexes with mercury, and states that both mercuric and mercurous ions react to form complexes; S. Augusti[5] gives the formula $Hg_4[Co(CNS)_6]$ to the mercurous cobalt thiocyanate, and states that 0·6 μg. of mercurous mercury is detectable.

Precipitation of mercuric iodide is another well-known means of identifying mercuric salts in solution, and there are several variations which have been used in carrying out the test.[1] The highest sensitivity is obtained by adding potassium mercuric iodide to a solution of a mercuric salt—

$$K_2HgI_4 + HgCl_2 = 2HgI_2 + 2KCl$$

The sensitivity of the test is 0·075 μg. of mercury.

Mercurous mercury may be detected under the microscope by precipitation of mercurous chloride, using hydrochloric acid as the reagent, but the reaction is made far more sensitive by taking a step further—i.e., by adding ammonia until the drop is alkaline, and observing the blackening.

Mercurous salts also form a red crystalline precipitate with potassium dichromate in neutral solution.

The operation of these microscope tests is well described by Chamot and Mason.[6] They also state that the diphenylcarbazide reaction, better known as a spot test, may be used as a microscope test. Mercurous ions yield a blue-violet amorphous precipitate, whilst mercuric salts give both the precipitate and some very deeply coloured disc-like shapes.

C. Mahr[7] has described the precipitation of mercuric ions from 0·1N hydrochloric acid by treating with a solution of Reinecke's salt, $NH_4[Cr(CNS)_4(NH_3)_2]$. The test will detect 2·5 μg. of mercury in the presence of 20,000 parts of copper or lead, or of 5,000 parts of cadmium.

The Application of Spot Tests to the Detection of Mercury.—The chief reagents used in this sphere up to 1933 were diphenylcarbazide, diphenylcarbazone, diphenylthiocarbazone (dithizone), *p*-dimethylaminobenzalrhodanine and the stannous chloride-aniline reagent. Not much more attention seems to have been given to the first two reagents. F. Feigl[2] gives a very full description of the procedure in all these tests, and has also included a spot test depending on the catalytic acceleration of the reduction of stannic salts. The reduction is carried out with hypo-phosphorous acid, but if a trace of mercuric salt is also present the reduction takes place very much more rapidly, and the formation of stannous tin, which indicates the presence of mercury, is detected by the cacothelin reagent.

A. Steigmann[8] has recently described the preparation and use of acetylcellulose membranes, both water-permeable and water-impermeable varieties. The membranes are impregnated with dithizone. At pH 2–2·5, the water-permeable membrane gives a yellow colour when treated with a solution of a mercuric salt, and the colour changes to red after fuming with ammonia and treating with potassium cyanide and caustic soda, in the order named. The application of a similar sequence of reactions to an impermeable membrane enables a decision to be made as to whether the mercury was originally present as mercuric chloride or combined with another anion.

Other Methods for the Detection of Mercury.—I. M. Korenmann[9] has worked out a very sensitive test which depends on the prevention of the development of the blue colour formed by starch and iodine. Mercurous, mercuric and silver ions all interfere, due to the formation of insoluble iodides. The reaction is said to be sensitive to 1 part of mercurous ion in 10^7 parts of solution, and to 4 parts of mercuric ion in 10^6.

E. A. Kocsis and G. Gelei[10] have described a test with 1 : 8-dihydroxynaphthalene-3 : 6-disulphonic acid, which will detect 0·2 mg. of mercuric, mercurous or silver ions.

M. J. Schapiro and M. I. Rud[11] have used phenylthiocarbimide to obtain precipitates or turbidities with a number of metal ions, including mercurous, silver and some of the noble metals. It would be expected that a similar substance of higher molecular weight—e.g., dithizone—would give a more sensitive reaction, and this is true.

M. Singh[12] has obtained colour reactions for mercury with dimethylaminophenyliminocamphor, and with the diethyl analogue.

G. Gutzeit and R. Monnier[13] have applied some azo-derivatives to the detection of mercuric ions.

Various investigators[1] have also applied spectrographic methods to the detection of mercury.

Determination of Small Quantities of Mercury

In this section, it is again convenient to divide the methods into groups. It will be noted that the gravimetric and colorimetric or nephelometric methods outnumber the volumetric methods. Special treatment has to be applied to each type of sample, in order to eliminate interfering matter, both organic and inorganic; above all, mercury must not be lost in this preliminary treatment. The reagents used in destroying organic matter are vigorous oxidising agents, and oxidation is carried out usually at room temperature. After oxidation, the mercury must be isolated quantitatively by deposition on copper or iron, by co-precipitation with an added quantity of another metal of the hydrogen sulphide group (e.g., copper or cadmium), or by other methods described in the text.

Gravimetric Methods

1. *Weighing as Mercury Tetraiodo Copper Ethylene Diamine.*—G. Spacu and co-workers[14] use this compound for the determination of 1·6 to 12 mg. of mercury. The precipitate is formed by the addition of copper ethylene diamine dinitrate to a solution of a mercuric

3 *Mikrochem.*, 1935, **18**, 223.
4 *Mikrochim. Acta*, 1938, **2**, 296.
5 *Gazzetta*, 1934, **64**, 169, 322.
6 "Handbook of Chemical Microscopy," vol. II, 2nd edition.
7 *Z. anal. Chem.*, 1936, **104**, 241.
8 *J. Soc. Chem. Ind.*, 1943, **62**, 43.
9 *Mikrochem.*, 1934, **14**, 181.
10 *Z. anorg. Chem.*, 1937, **232**, 202.
11 *J. Appl. Chem. Russia*, 1938, **11**, 140.
12 *J. Indian Chem. Soc.*, 1938, **15**, 402.
13 *Helv. Chim. Acta*, 1933, **16**, 233.
14 *Z. anal. Chem.*, 1929, **78**, 243.

salt in presence of excess of potassium iodide and neutral or ammoniacal tartrate, and affords a ready separation from copper, and from other metals which form soluble tartrate complexes.

2. *Weighing as the Metal.*—Cucuel has reviewed several methods of determining by weighing as the metal; by weighing after deposition on copper, gold and platinum, and reweighing after ignition. All these methods[1] suffer from severe disadvantages where micro-quantities of mercury are being dealt with, either through surface oxidation in the case of copper or through loss of mercury by vaporisation between the weighings in the case of platinum. The best method is to distil the mercury from the metal on which it has been deposited into a glass capillary, where it is condensed, then to weigh the mercury and capillary together. The capillary is then ignited strongly and reweighed. W. H. Rauscher[15] reduces compounds of mercury in organic, inorganic or pharmaceutical preparations by heating for 5 mins. with ethanolamine or diethanolamine. Stronger reduction is obtained, if necessary, by addition of dioxan and sodium. The product of reduction is mercury, which may be collected and weighed in a Pregl halogen tube. J. G. Fife[16] determines quantities of mercury, between 0·7 mg. and 7 mg., in brass by internal electrolysis.

3. *Weighing as Mercuric Sulphide.*—Cucuel gives references to this means of determining mercury, and states that it is suitable for determining from 2 mg. to 15 mg. of the metal.[1] C. Newcomb, S. R. Naidu and K. S. Varadachar[17] separate mercury quantitatively from other metals, *in viscera*, by destroying organic matter with a hot mixture of sulphuric and nitric acids and distilling the residual liquid until fumes of sulphur trioxide appear. The distillate is collected, and distillation of the residue is continued in a current of air and hydrogen chloride. The distillates are combined, and the mercury is precipitated from them as mercuric sulphide, the precipitate is dissolved up in bromine water and reprecipitated.

4. *Precipitating with Reinecke's Salt and Weighing the Product.*—C. Mahr[7] has described the precipitation of mercuric ion, both quantitatively and qualitatively. In the determination, the precipitation is made from hot 0·1N hydrochloric acid solution, by treating with a solution of Reinecke's salt. The crystals may be dried at 105°, and weighed, or may be ignited to Cr_2O_3 and weighed as such. The precipitate has the formula $Hg[Cr(CNS)_4(NH_3)_2]_2$, and provides a further means of separating mercury from copper, lead and cadmium.

5. *Precipitation with 2-chloro-5-thiol-7-methoxyacridine.*—S. J. Das Gupta[18] determines 10 mg. to 20 mg. of mercury by precipitating with the above reagent. The precipitate can be washed, and dried at 100° before weighing.

Colorimetric and Nephelometric Methods

1. *Reaction with Diphenylcarbazide.*—The determination of mercury by using this reagent is surrounded with difficulties due to the instability of the colour, the reaction with other metals, and the influence on the colour of chloride ion. The colour produced with mercury is really due to diphenylcarbazone, which is derived by atmospheric oxidation of the diphenylcarbazide.

2. *Reaction with Dithizone.*—This reaction has been discussed by the author in a previous article on the use of dithizone as a microchemical reagent.[19] Although the method has limitations, it can be used with some success for the determination of up to 100 μg. of mercury, particularly when interfering ions are first removed.

3. *Reaction with p-dimethylaminobenzalrhodanine.*—The reagent is well known as a means of detecting silver and mercury, and has been adapted to the estimation of mercury, in a concentration not exceeding 0·2 mg. per 100 ml., by N. Strafford and P. F. Wyatt.[20] Mercury must first be separated from other metals.

4. *Prevention of the Development of the Starch-iodine Colour.*—The method already mentioned for the detection of mercury worked out by I. M. Korenmann,[9] has also been applied quantitatively, and should be very well suited to determining mercury in quantities of a few micrograms.

5. *Colorimetric Determination with Ammonia.*—M. Rangier and H. Rabussier[21] claim to have obtained a specific micro-method for determining mercury in biological material. Organic matter is destroyed with *aqua regia* and potassium chlorate. Calcium phosphate is then added to the acid solution and mercury is precipitated with the phosphate by adding caustic soda. The mercury in the precipitate is redissolved in dilute hydrochloric acid and is then co-precipitated as sulphide, along with added cadmium. The precipitate is dissolved in dilute *aqua regia*, the solution nearly neutralised with caustic soda, treated with excess potassium iodide, and then with more caustic soda until alkaline. The cadmium hydroxide precipitate is filtered off, and the colorimetric determination with ammonia is then carried out.

6. *Nephelometric Determination with Reinecke's Salt.*—A. A. Sankov[22] has used the precipitation of the complex formed by the reaction of mercuric salts with Reinecke's salt as the basis for a nephelometric method for mercury—0·2 μg. to 10 μg. of mercury per litre of solution are determined.

7. *Nephelometric Method, Using Potassium Iodide and Strychnine Sulphate.*—S. I. Sinjakova[23] has determined 0·2 μg. to 10 μg. of mercury by this means. The importance of not having an excessive concentration of potassium iodide, which causes rapid coagulation, must be observed.

Volumetric Methods

1. *Potentiometric Titration with Potassium Iodide.*—K. Schwarz and T. Kantor[24] have determined 1 μg. to 1,000 μg. of mercury with an accuracy of ±1 to ±3%. The whole of the mercury in solution is first converted into mercurous salt by shaking with metallic mercury. The solution is decanted and washed into a special titrating vessel, and is treated with perchloric acid solution until the pH is 1·5. Potassium iodide solution is the titrant, and amalgamated platinum is used as the indicator electrode.

2. *Photometric Titration with Sodium Sulphide.*—S. Hirano[25] titrates small amounts of a neutral chloride or nitrate solution of mercury with sodium sulphide solution. Gum arabic is used as a protective colloid,

15 *Ind. Eng. Chem.* (Anal.), 1938, **10**, 331.
16 *Analyst*, 1938, **63**, 650.
17 *Analyst*, 1935, **60**, 732.
18 *J. Indian Chem. Soc.*, 1941, **18**, 43.
19 METALLURGIA, 1944, **29**, 217.
20 *Analyst*, 1936, **61**, 528.
21 *Compt. rend. Soc. Biol.*, 1935, **119**, 1052.
22 *Compt. rend. Acad. Sci., U.S.S.R.*, 1938, **20**, 373.
23 *Z. anal. Chem.*, 1935, **100**, 190.
24 *Mikrochem.*, 1933, **13**, 225.
25 *J. Soc. Chem. Ind. Japan*, 1935, **38**, 646.

and the attainment of maximum turbidity of the system indicates the end-point.

3. *Application of the Reaction of Mercuric Salts with Tetraphenylarsonium Chloride.*—Mercuric chloride reacts with tetraphenylarsonium chloride, in aqueous solution, according to the equation :—

$$2AsPh_4 + HgCl_4 = [AsPh_4]_2[HgCl_4]$$

H. H. Willard and G. M. Smith[26] have applied this reaction to the determination of 0·5 mg. to 100 mg. of mercury. The complex is precipitated from 1 M to 2·5 M. aqueous sodium chloride, in which it is insoluble, by using a measured excess of reagent. The excess reagent is titrated potentiometrically with iodine. The values obtained are accurate to 0·06 mg. of mercury.

4. *Titrations with Standard Iodine and Thiosulphate.*—These have been discussed elsewhere.[1, 27]

Other Methods for Determining Mercury

1. *Micrometric.*—The isolation of mercury by deposition on some other metal, followed by distillation and collection of the condensed mercury droplets, has been applied quantitatively by several investigators.[1, 28, 29] The method is said to be useful in the range 0·1 μg. to 2,000 μg. of mercury. Above the latter limit, droplets are no longer spherical.

2. *Spectro-analytical Determinations* have been employed to determine amounts of mercury down to 1·6 μg., but the claims as to the accuracy of the results are varied.[1, 30, 31]

3. *By Using Radioactive Mercury as a Tracer.*—J. W. Irvine, jun., and C. Goodman[32] have determined concentrations of mercury in air, down to 10 μg. per cubic metre, by this means.

In the foregoing, an attempt has been made to indicate the recent developments in the micro-analytical chemistry of mercury. The treatment of each point has necessarily been brief, but the range of usefulness of the methods discussed should serve as a guide when a choice of method has to be made.

26 *Ind. Eng. Chem.* (Anal.), 1939, **11**, 269.
27 C. A. Mitchell. "Recent Advances in Analytical Chemistry," vol. II, p. 38 (1931).
28 A. M. Fraser. *J. Ind. Hygiene*, 1934, **16**, 67.
29 V. Majer. *Chem. Listy*, 1934, **28**, 169.
30 S. P. de Rubies and M. A. Bargues. *Z. anorg. Chem.*, 1933, **215**, 205.
31 C. Sannié and V. Poremski. *Bull. Soc. chim.*, 1939 (v), **6**, 1401.
32 *J. Appl. Physics*, 1943, **14**, 496.

Micro-Determination of Density

A MICRO-PYKNOMETER has been described * which can be used for the determination of the density of 0·01 ml. or less of liquid.

In order to construct the apparatus, glass tubing is, in the first instance, drawn out to approximately 2 mm. external diameter and 0·5 mm. internal diameter. This is further drawn out in a large cool flame so that a bulb is left consisting of a 2 cm. portion of the original capillary tube, with, on one side of it, a 5 cm. length of even finer capillary, and on the other side, a 17 cm. length of the same fine capillary. This latter should approximate to 0·4 mm. external diameter. The complete length of tubing is now bent at its central point to form a V with a 60° angle. This means that the final apparatus is a 60° V with a bulb in the middle of one limb, each limb being 12 cms. long.

Four pins are arranged on a vertical board so that they also outline a 60° V. When the pyknometer is dropped into the rack thus formed it should always lie against the board in the same position. Scales are drawn on the board for a length of 3 to 4 cms. from each end of the pyknometer, and conveniently graduated in millimetres.

Calibration of the instrument may be carried out with water. The instrument is almost filled by surface tension and siphoning, and the board on which it hangs is tilted somewhat out of the vertical, so that the meniscus of the liquid reaches one end of the capillary where it is held by surface tnesion. A note is made of the reading on the other limb, and the whole is weighed. By allowing the pyknometer to stand in the tilted position, slow evaporation will take place at the tip of the full limb, while capillary attraction will maintain the meniscus there. Occasional readings of the changing level in the other limb, together with the weighings will give a calibration curve for one limb, and this may be repeated for the other limb.

Alternatively, the tube may be almost filled with mercury, placed in the rack, and coincidental readings on the two limbs, when the tube is tilted at various angles, are made. The mercury is subsequently weighed.

For a determination of the density of a liquid, the pyknometer is filled so that the liquid level lies at least one centimetre from each end when hung vertically in the rack. If this point is observed, negligible evaporation takes place, even with the most volatile liquids—no appreciable loss in weight occurred in 15 minutes with methyl iodide under these conditions.

To fill the pyknometer with a viscous liquid the ordinary method may not suffice, and it will be necessary to apply suction. This can be done by inserting the instrument in a cork, for which purpose use is made of a hypodermic syringe. The syringe needle is inserted through a small axial hole in the cork, and the end of the pyknometer placed in the needle. By withdrawing the needle carefully, the leg of the pyknometer is left threaded in the cork, which may then be inserted in a glass tube for connection to suction.

* Houghton, *Analyst*, 1944, **69**, 345.

The Determination of Calcium in Magnesium

THE estimation of small amounts of calcium in magnesium metal of the order of 0·0005% to 0·1% is not satisfactorily carried out by any chemical method. A satisfactory determination can be made spectrographically,* using a high voltage spark between an electrode of the metal in question and a graphite electrode. The production of a calibration curve for the method presented some difficulty, but was solved by the use of standard solutions containing magnesium with a known proportion of calcium. Graphite electrodes, impregnated with these solutions were first sparked and curves drawn up from the results. Then a number of specimens of magnesium metal containing traces of calcium were sparked under the standard conditions, the calcium content of these being determined by calculation from the known solution curves. These samples of magnesium, with their determined proportions of calcium, then served as standards on which to base the method for routine analysis.

* Whitehead and Boyle, *Ind. Eng. Chem. Anal. Ed.*, 1944, 16, 455.

Bimetal Performance at 800° F.

By P. R. Lee

THE problem of successfully using bimetals at temperatures below 600° F. is relatively simple when compared to the problems presented at temperatures of about 800° F. At high temperatures, such factors as bimetal manufacturing technique, preliminary heat-treatment of the finished bimetal blanks prior to assembly, and both internal and external-stress become very important while scaling or oxidation of the bimetal is also accentuated. At lower temperatures details of manufacture and internal stresses are usually totally disregarded and preliminary heat-treatment given only minor consideration. To ascertain the behaviour of bimetals at elevated temperatures, a special testing fixture was built whereby various bimetal specimens could be simultaneously tested at the same temperature for long periods of time.

The bimetals to be tested were made up into small narrow specimens as shown in Fig. 1, A. With the low-expansion component on top and in a horizontal plane, one end of each bimetal specimen was solidly clamped to a rigid support while at the free end a fixed weight was suspended as in Fig. 1, B. The whole fixture was placed in a constant temperature oven held within ± 2° F. of the specified operating temperatures. Once a week the oven was cooled to room temperature, all weights carefully removed, and each bimetal specimen placed in a separate calibration fixture where they were accurately checked by micrometers for change of shape by measuring the movement in the free end of the bimetal. The general relationship between time and change of shape for either a loaded or unloaded specimen is shown in Fig. 2.

Internal stresses introduced during manufacture by constrained heating, free heating, rolling or bending are far from being small and seriously affect bimetal performance, especially when high temperatures are involved where elastic limits are somewhat reduced. The direction and magnitude of these stresses is important because they may either substantially increase or decrease the stability of the bimetal under actual service conditions. To show what internal stresses were present commercial bimetals were dipped into a chemical solution which completely dissolved either the high- or low-component without affecting the remaining component. In every case tested it was found that the remaining component was not flat as was the composite materal and from the resultant shapes obtained the magnitude of the internal stresses existing in commercial bimetals could be determined.

Better temperature stability is obtained if bare bimetal blanks prior to assembly are aged at a temperature

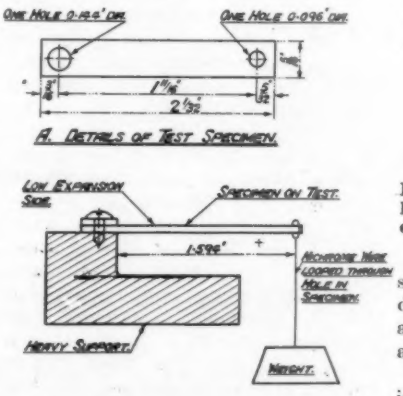


Fig. 1.—Details of specimen and testing method.

slightly in excess of their final intended operating temperatures, and such treatment is always very important for bimetals operating at high temperature. Curves showing the effect of preliminary heat-treatment on bimetal performance at 800° F. were obtained on specimens cut out from the same bimetal strip, 0·020 in. thick, so that internal stresses originally present from manufacture should be approximately the same in each. Heat-treatments given consisted of ½ and 2 hours at 900° F. and 2 hours at 1400° F. To show the great variation which exists in various bimetals, curves were also obtained for three different bimetal alloys, 0·020 in. thick, all heat-treated for 20 minutes at 900° F. and operating at 800° F. This test showed that, when subjected to high temperatures without loading, bimetals reacted tremendously, whereas monometals usually showed very little if any change. Tests were also carried out to evaluate the internal stresses present in bimetal strip and to show the relationship in different bimetals between externally applied load stresses and permanent set at temperatures of 600° F. and 800° F.

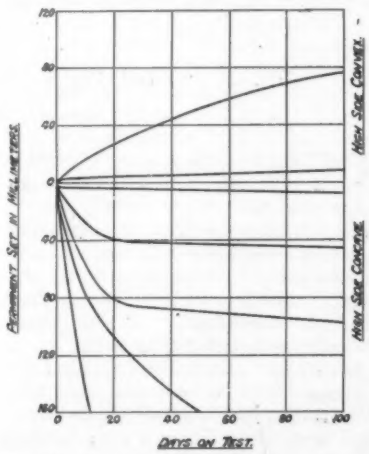


Fig. 2.—Curves showing general relationship between time and change of shape for loaded and unloaded specimens.

The various tests showed that internal stress in bimetals and the permanent changes which occur during preliminary heat-treatment are extremely variable and not only do the various bimetal alloys vary immensely but so also do different lots of the same bimetal alloy and thickness. As either or both the time and temperature of the preliminary heat-treatment is increased, the permanent set so created due to the heat-treatment is also increased. Assuming a fixed heat-treatment temperature and time, bimetals which show the most changes of shape during heat-treatment also show the most changes when used in service unloaded and at temperatures

From *Metals and Alloys*, 1944, vol. 20, No. 2 pp. 346–349.

above 500° F. On most commercial bimetals, ageing temperatures usually tend to cause a lowering of bimetal operating temperatures, because the high component tends to become convex, although there are some notable exceptions. If the heat-treating temperature is above the final operating temperature, increasing either the time or the temperature of heat-treatment tends to reduce the permanent set encountered in service. In many cases, however, if the time and temperature are increased sufficiently, the permanent set in service may be eliminated or even reversed in direction.

Most commercial bimetals show less change in bimetal calibration if loaded slightly in an opposite direction to thermal stresses than if used without any external loading at 800°F. Material improvement in bimetal performance at elevated temperatures is possible by using the maximum permissible bimetal thickness. The direction and magnitude of permanent bending at 800° F. in unloaded bimetals appears to be influenced by the relative hardness and relative modulus of elasticity of the two expansion components. The maximum load stress to which bimetals should be subjected at any temperature depends on the maximum permanent set allowable. Tests carried out indicate that if 25,000 pounds per sq. in. has been used at 600° F., a limit of about 4,000 pounds per sq. in. should be used at temperatures of 800° F. The proper selection of bimetal alloys and their heat-treatment is therefore very important when using bimetals above 600° F.

Steel Castings—Centrifugally Cast

By J. W. Moore.

CENTRIFUGAL casting of steel is a relatively recent development that has made rapid strides due to war conditions and which looks like continuing into the post-war era. The broad term, "centrifugally cast," embraces three methods of casting: "True centrifugal," "semi-centrifugal" and centrifuging. The "true centrifugal" method is spinning the casting about its own axis and using centrifugal force to hold the metal on the wall of the mould, thus forming the inside without the use of a centre core. "Semi-centrifugal" casting is spinning a casting about its own axis—usually about the vertical axis. If the casting has a centre cavity this cavity is usually formed with a centre core, and the casting is fed by a centre gate passing around this core. In "centrifuging" the moulds forming the useful castings are positioned near the periphery of the revolving table and the metal is poured into a gate on the axis of rotation and is fed into the mould by radial sprues. Centrifugal force is used merely to provide liquid pressure.

The choice of whether to produce a steel casting by one of the three methods or by the conventional static method should be determined by the available equipment, size and shape of the casting, and the number of casting to be produced for any particular part. Satisfactory steel castings may be produced by all the centrifugal methods and by several different ways by each method. While the choice of method for producing some shapes is debatable, there are certain types of parts that are suitable for centrifugal casting. Radial engine cylinder barrels, cylinder sleeves, bearing backs and other short cylindrical parts having straight cylindrical insides, and required in large volume, lend themselves especially to cylindrical casting in metal moulds spun on the horizontal axis. Parts which are symmetrical, having a hollow centre, such as flywheels, gears, track wheels, etc., may be readily classified as suitable for semi-centrifugal casting, while odd shapes, such as levers, cams, brackets, and other solid parts commonly produced from drop forgings may be economically produced from centrifuged castings. Steel castings produced by the centrifugal method in metal moulds and the semi-centrifugal method in sand-lined moulds are especially adaptable for production of parts which may also be produced from steel forgings and hot rolled shapes.

The chief field for steel castings, centrifugally cast, is for relatively large volume requirements and chiefly in competition with forgings and wrought steel products than with static steel castings. Steel castings, cast centrifugally, should be consistently cleaner and sounder than static castings and should give a higher production yield resulting from fewer rejections due to defects. Compared with steel forgings, steel castings, centrifugally cast, have the following advantages: They may be cast nearer to finished dimensions with consequent reduction in process machining costs, lower capital investment for production equipment; and freedom of marked directional properties.

Tests have shown that S.A.E. 4140 steel castings, centrifugally cast, to be comparable with 4140 steel forgings as to ultimate tensile strength, yield strength, reduction of area, polished and notched bar fatigue strength, and impact resistance. Some tests have shown higher notched bar fatigue strength for centrifugal castings than for forgings of comparable chemical composition. Tests have also shown the creep characteristics of centrifugally cast steel to compare favourably with rolled and drawn steel in four low and intermediate chromium-molybdenum compositions. Centrifugally cast steel tubes are also comparable to rolled and drawn tubing in the ability to be rolled into seal joints in header boxes required for high pressure and high temperature cracking still in service.

In centrifugal steel casting, the chemistry of the steel, melting and other metallurgical factors, as well as proper feeding of the metal, rate of pouring, speed of spinning, controlled directional solidification, and other foundry techniques, all dictated by experience, are essential to the production of satisfactory castings.

From *Metal and Alloys*, 1944, vol. 20, No. 2 pp. 365–368.

Corrosion of Pipe in Oil Industry

THE serious corrosion of pipes and fittings of high-pressure condensate wells, which has cost the petroleum industry hundreds of thousands of dollars, will be studied by Battelle Institute, Columbus, Ohio, under a research programme recently initiated for the Natural Gasoline Association of America. The programme is a co-operative effort to determine the cause and means of eliminating one of the most baffling corrosion phenomena. First reported two years ago, the corrosion has since been found in a large number of condensate fields and has defied all individual efforts of remedy.

Occurring as it does in high-pressure wells, most of which range in depth from 7,000 ft. to 10,000 ft. (2,100 m. to 3,000 m.) or more, this corrosion creates an unusual hazard. The corrosion is all internal, and cannot be observed except by tear-down inspection. It is not continuous throughout

From the *Iron Age*, September 14, 1944.

the well fittings, but is spotted at unexpected locations in the surface connections, or may appear 400 ft. (120 m.) down the tubing. In some extreme cases, destruction of fittings has been so rapid that replacement has been necessary within 90 days. The project will be continued for at least three years, because of its complex nature. The laboratory work at Battelle will be supplemented by full-scale experiments in the field. The data and activities of the research groups will be co-ordinated by a central corrosion Research Project Committee, which will also serve as a clearing house for corrosion research data developed by individual companies, the U.S. Bureau of Mines, and the American Petroleum Institute.

The Metallography of Copper-Lead

Improved "Chrome Regia" Method

By R. W. K. Honeycombe, M.Sc.

DURING the war, special metallographic methods have been developed in Australia by the Lubricants and Bearings Section of the Council for Scientific and Industrial Research for the examination of copper-lead bearings used in aircraft. These methods are not intended to replace visual and radiographic examination, but rather to supplement them.

Alloys of copper and lead are really mixtures of these metals, since they are only partially miscible in the liquid phase and practically immiscible in the solid state. The difference in their hardness and rate of oxidation also leads to difficulties in polishing by any normal technique, but these can be overcome by Grange's method of using a "chrome regia" etching procedure. Chrome regia is a solution of chromium trioxide and hydrochloric acid in water, but certain modifications of the former technique have been introduced in the present method of using it, which is as follows :—

The specimen (which is usually mounted in bakelite) is wet ground on a series of successively finer Hydro-Durexsil emery papers down to 600-grit paper. The specimen is then etched in the chrome regia etchant (the composition of this etchant will be discussed later) for approximately 5 secs. Most efficient etching is obtained by swabbing the surface of the specimen with cotton wool soaked in the etchant. This treatment dissolves the surface layer of copper and is controlled to bring the copper and lead to the same level. The specimen is then transferred to a disc rotating with a peripheral speed of 600 ft. per min., which is covered with "Selvyt" cloth and impregnated with elutriated alumina with a settling rate in water less than 1 in. in 4 hours. The specimen is polished for about 20 secs. and then is re-etched. This procedure is repeated several times until all scratches have been removed and the etching time has been so adjusted to leave the copper and lead at the same surface level. After the final etching, the specimen is swabbed for 12 to 2 secs. with cotton wool soaked in a 10% solution of hydrochloric acid in alcohol. This removes an orange-coloured chromate film which appears on the surface of the copper-lead alloy. The specimen is then rinsed in running water. The final stage consists in rubbing the surface gently with a piece of clean cotton wool soaked in ethyl alcohol. This procedure removes any tarnish from the lead and gives it a blue-grey lustre; furthermore, any slight relief of the lead constituent can be eliminated. For successful results, careful adjustment of the relative polishing and etching times is necessary. Some alloys tend to "core" markedly, so that in these cases the etching and polishing times are shortened proportionately.

Two etchant compositions are used :

	I.	II.
Chromic acid (AR)	25 grms.	25 grms.
Hydrochloric acid (conc.) ...	2 ml.	5 ml.
Sulphuric acid (conc.)	2 ml.	5 ml.
Water	500 ml.	500 ml.

Etchant I is more suitable for silver-bearing copper-lead alloys, and type II for tin-bearing alloys of the same general type, the principal criterion of a satisfactory etchant being its ability to dissolve only the copper-rich phase finally bringing it to the level of the lead-rich phase without causing undue pitting or irregularity on the surface.

Tin-rich copper-lead alloys are best etched with acid ferric chloride of the following composition, 5 grms. ferric chloride, 50 ml. of concentrated HCL, and 100 ml. of water.

As this etchant attacks the lead phase, it is preferable to use the ordinary etch-polish method up to the final stage in the preparation of a specimen. The final etch is then done with the acid ferric chloride solution. There is no need to proceed with any further treatment, as the lead is automatically polished by the etchant. Another advantage of this type of etchant is that it etches steel. This reduces the amount of the relief, which is often obtained between a copper-lead alloy and a steel backing, and allows more accurate examination of the bond.

From *Proc. Australian Inst. Min. Met.*, No. 133, Mar., 1944.

Improved Copper-Plating Process

AN improved high-speed copper-plating process which reduces operating costs and speeds up production rates is announced by E. I. du Pont de Nemours and Co. This improvement is a development of the copper-plating process introduced by the company in 1938. The original method plated heavier deposits of copper in a shorter time than had before been possible. It utilised a carefully compounded and controlled sodium copper cyanide bath operating at 100% current efficiency and at increased current densities. The new gains were achieved by working out a method of substituting potassium cyanide and other potassium salts for the sodium salts formerly used with still further increases in current densities. Development of methods for producing the potassium salts in this country, and technical advances in their use in plating baths, made the substitution possible.

Makers of tanks, planes, motorised equipment and other military and naval items have adopted the new process for copper-plating numerous engine parts and other articles. Of major importance is the use of the process as a stop-off or mask in selective case-hardening of steel parts to increase wear resistance. This allows certain portions of machine parts to be hardened to resist shock or wear, while the copper-masked sections are left softer and tougher. Copper is likewise valuable as a corrosion-resistant plate and as an undercoat for decorative finishes, such as nickel and chromium. The ease with which it can be buffed compared to steel, cuts costs and speeds-up production of highly polished articles.

Science Service.

Heat-Treatment of Alloy Steels

[A Composite]

THREE papers were presented at the 1943 Annual Convention of the American Society for Metals which dealt with the heat treatment of alloy steels. The first[1], by G. F. Comstock, is concerned with some effects of heat-treatment on low alloy titanium steels, the second[2] reports an investigation on the strength of heat-treated alloy steel bolts by G. Sachs, P. S. Cole, and R. A. Roth, while the third[3] reports the effect of quenching bath temperature on the tempering of high-speed steel by P. Gordon, M. Cohen and R. S. Rose.

In the investigation on titanium steels, an ingot of low-carbon titanium steel, containing 0·13% carbon, 0·48% manganese, 0·18% silicon and about five times as much titanium as carbon, was forged at 985° C. and another of the same steel was first soaked for 4 hours at 1175° C., both being finished at about the same temperature. A marked increase in yield strength of 10 tons per sq. in. was obtained, due to soaking, but was lost on normalizing at 925° C., due to the titanium carbide separating from the solid solution in the previously superheated bar. A more extensive investigation of the effects of high temperature heat-treatment on an S.A.E. 1040 steel with 0·35% titanium in comparison with two similar steels without titanium, one, however, containing 0·1% of vanadium. The composition and austenitic grain sizes of these steels are given in Table I. Tensile and impact test results showed the titanium steel to become stronger but less ductile and tough as the titanium carbide passed into solution above 1010° or 1040° C., while similar changes occurred in the vanadium steel below 955° or 1010° C., and the non-alloy steel did not become stronger after high temperature treatment. Similar change due to solution effects at high temperature were found in S.A.E. 4140 steel containing as little as 0·053% of titanium, when there was an appreciable increase in strength, as the normalising temperature was raised from 900° to 1175° C. In a steel of this type, containing 0·1% of titanium, the tensile strength was also greatly improved, although the ductility and impact resistance were low when the high-temperature treatment was applied after forging. A marked increase in yield and tensile strength was found in a low-alloy high-strength plate steel, containing 0·14% carbon, 1·24% manganese, 0·36% copper, with increasing titanium content. After normalising, the increase in strength with titanium was still perceptible, though much smaller, but the reduction of area and impact values of the normalised specimens were improved with high titanium.

In general, normalising below 1095° C., titanium improves the ductility and impact resistance, but with comparatively limited, if any, increase in yield and tensile strengths. With treatments above 1095° C., titanium increases the yield and tensile strength as much as 50%, but gives lower ductility and impact resistance. The decrease in the latter properties may be corrected by mechanical work, such as forging, without serious impairment of the improved strength. The difference in properties resulting from these two methods of heat-treatment are probably due to a difference in the mode of titanium carbide dispersion.

TABLE I.—COMPOSITION AND AUSTENITIC GRAIN SIZE.

Steel	Composition				A.S.T.M. Grain Size Normalized at			
	C	Mn	Si	Alloys	920° C.	984° C.	1088° C.	1226° C.
O	0·36	0·68	0·22	none	3	3–4	2–3	1–2
T	0·37	0·63	0·27	0·35 Ti	8–9	8	7–8	3–4
V	0·40	0·66	0·19	0·10 V	8–9	6–7	3	0–1

In the experiments by Sachs, Cole and Roth, dealing with the strength of heat-treated alloy steel bolts which were subjected to testing conditions simulating a wide range of service conditions, tests were carried out on commercial aircraft bolts fabricated from S.A.E. 2230 steel, 0·28 to 0·30% carbon, 0·6 to 0·8% manganese and 3·25 to 3·75% nickel. Tests were made at various strength levels, as determined by tempering after proper hardening, using various shapes of bolt head, which were found more prone to rupture than the thread in the range of conditions conducive to brittle fractures; and various types of loading, i.e., regular tension and tension with superimposed bending.

It was found that in tension, with little or no superimposed bending, ductile breaks through the threads occurred in the as-quenched bolts, which showed brittle failures under the head at low and widely scattered loads, thus indicating greater notch sensitivity at this point than in the threads. Those failures were prevented by adding a "stress relief" radius from shank to head. Superimposed bending at either the head end or thread end caused brittle failures in these sections at considerably reduced loads. For a 10° tapered shim or washer under the head, brittle failures occurred at the bend for tempering temperatures below 425° C., or at strengths above 70 tons per sq. in. For a shim under the nut, failures occurred at very low loads by stripping of the threads in an apparently brittle manner and only for tempering temperatures above 650° C. did the thread reach approximately the same strength when tested with a shim as without. For tempering temperatures below 205° C brittle failures were obtained through a 0·002-in. radius notch placed near the nut and tested with a shim under the nut.

Brittle breaks under the heads were suppressed by the use of a relief groove. The as-quenched bolt showed a lower tensile strength and a greater tendency towards brittle failures with superimposed bending than a bolt stress relieved by tempering at 95° to 205° C. Bolts of the selected steel and size could be heat-treated to 100 tons per sq. in., if straining in service was in pure tension, but 78 tons per sq. in. was the maximum safe limit if superimposed bending was present, without a fillet was used under the head.

In the third investigation, the relationship between the quenching bath temperature and the tempering kineties of a 6.5–1·5 high speed steel containing 0·805% carbon, 5·87% tungsten, 4·07% chromium, 4·84% molybdenum and 1·5% vanadium, was studied by means of magnetic dilatometric and hardness measurements. In particular, the retained austenite decomposition on tempering was followed as a function of time and temperature during single, double and multiple tempering. Test specimens were austenitised at 1220° C., dipped momentarily into molten lead at

565° C., and quenched in hot oil or molten metal at the predetermined arrested cooling temperature for ten minutes to bring them to the quenching-bath temperature without causing appreciable thermal transformation of the austenite. Tempering was then carried out in a lead bath, followed by air cooling.

It was found, if the austenitised steel was cooled to room temperature prior to tempering, that the retained austenite could be decomposed by tempering for 2½ hours at 565° C., but if the hardening quench was arrested above room temperature, correspondingly large quantities of austenite were transferred to the tempering process and appreciable amounts remained after such tempering treatment. Extending the time at 565° C. beyond 2½ hours did little to reduce residual austenite, while high tempering temperatures resulted in considerable softening. Completed decomposition of the retained austenite, however, was achieved in 2½ hours at 565° C. by double or multiple tempering, even if the quenching-bath temperature was high.

Repeated tempering after arrested quenching and also after quenching to room temperature, caused a significant increase in the transverse strength of the steel. Whenever the quenching-bath temperature was appreciably above room temperature and a double tempering was required to bring about decomposition of the retained austenite, a third tempering resulted in further improvement of the strength properties. Although highly acceptable values of transverse strength were thus obtained, the highest strength values were secured when the quenching-bath temperature was as low as possible.

1 *Trans. Amer. Soc. for Metals.* 1944, vol. 33, pp. 324-336.

2 *Trans. Amer. Soc. for Metals.* 1944, vol. 33, pp. 396-406.

3 *Trans. Amer. Soc. for Metals.* 1944, vol. 33, pp. 411-440.

Notched Bar Tensile Test Characteristics of Heat-Treated Low-Alloy Steels

By G. Sachs, J. D. Lubahn and L. J. Ebert.

INVESTIGATIONS on notched alloy steel tensile test bars have revealed severe embrittlement if the strength of the steel exceeds 100 tons per sq. in. The notch strength values of such high-strength steels scatter considerably. A systematic investigation was therefore initiated in order to determine the influence of various factors on the results of the notched bar tensile test. In order to eliminate bending stress, which considerably reduce the notch strength a new concentric test fixture was developed.

Tests were carried out on S.A.E. 3140 steel containing 0·40% carbon, 1·37% nickel, 0·66% chromium, 0·76% manganese and 0·26% silicon. This steel was oil quenched from 830°C. and tempered for one hour at various temperatures from 260° to 650° C. to different "strength levels," i.e., average tensile strengths ranging from 120 tons and 60 tons per sq. in. Decarbonisation at the root of the notch was found to raise the notch strength, and this and other surface effects due to heat-treatment were removed by careful machining, grinding and polishin of the notch fillet.

From *Trans. Amer. Soc. for Metals.* 1944, vol. 33, pp. 340-391.

The first part of the investigation dealt with the effect of notch radius. The scattering influence of eccentricity was kept at a minimum by the use of the special accuracy in the final machining of the test specimens and by testing the specimens in fixtures which were designed and constructed with the primary objective of obtaining concentric loading. In each series of tests, the notch radius was varied from zero (sharp notch) to infinity (unnotched specimen) and the notch strength, the notch ductility and the fracture stress determined.

The results obtained showed that the transverse elastic strain, the notch strength and the notch ductility, of a notch-ductile steel, having a strength level below 100 tons per sq. in. were almost independent of the notch radius between zero and $\frac{1}{32}$ inch. This indicated that the transverse stress or triaxiality in the restrained notch section was little affected by the notch radius within this range. It was only when the notch radius became rather large that the notch strength and correspondingly the transverse tension decreased with increasing radius, while the notch ductility simultaneously increased. The notch strength of a steel having a high strength level, however, was larger the larger the notch radius, because of the correspondingly smaller stress-concentration in the notch section. The notch strength increased up to a notch radius of $\frac{1}{32}$ in., and then decreased, because of the decreasing transverse tension.

In the second part of the investigation, notched bar tests were made with an eccentric test fixture to determine the effects of eccentricity. This fixture consisted of a modification of the usual ball-seat type of fixture and incorporated certain features that made it possible to produce different amounts of eccentricity by only minor adjustments. In each series of tests the eccentricity was varied from zero (concentric tests) to approximately 0·50 in. and for a few strength levels to 1½ in. The results obtained showed that the superimposition of bending on tension generally reduced the notch strength, the higher the strength level or the smaller the notch ductility, and the larger the eccentricity. Above a certain eccentricity, the notch strength of a steel becomes smaller, the higher the strength level, i.e., the eccentric notch strength measured primarily the inherent (notch) ductility of the steel, and this was explained readily by theoretical conceptions.

Metals that Resist Heat and Humidity

By W. L. Maucher and B. W. Jones

FOUR groups of 18 selected metal specimens were subjected to combined high-temperature and high-humidity in a refinery on the Gulf Coast to test the effects of the corrosive atmosphere. The test covered two groups of metals located indoors and two outdoors for about 18 months.

The following conclusions were arrived at: When electroplated on copper tin appears to stand up the best. The cadmium coating was completely gone and the silver coating was strongly attacked. The lead plating did not look so bad on the surface but on closer inspection deep pits were noted in the copper-base metal. Of the chromium alloys tested 18–8 stainless steel and Nichrome V averaged about the same and were the best in this test. The 25% chromium steel was not quite as resistant and the 12% chromium steel was decidedly

From a paper read before a recent Pittsburgh meeting of the American Soc. of Mechanical Engineers.

inferior to the three other alloys subjected to the test.

While aluminium untreated showed a uniform corrosion coating and the anodised aluminium had scattered pits, this metal gave nearly as good results as the 18–8 stainless steel. It is believed that aluminium, anodised or otherwise, properly treated for painting and then given two or more coats of aluminium paint, provides one of the most corrosion-resistant combinations available.

Copper and high-copper alloys have low resistance to corrosion in this kind of atmosphere, and should not be used unless protected by some effective coating. Nickel was not attacked as much as Monel metal. The marked corrosion of unprotected cold-rolled steel indicated the severity of the corrosive atmosphere to which it was exposed and emphasised the necessity of maintenance-painting on any steel parts.

Lead showed up unusually well. On silver, although it was heavily attacked there was no sign of pitting or etching. The metal underneath the corrosion film was very smooth. On large knife switches, the silver surfaces continued to carry their currents satisfactorily.

Radium Radiography

[A Composite]

AT the Annual Meeting of the American Society of Testing Materials held in 1943, a series of papers[1] were presented by A. Morrison and E. M. Nodwell to the Society's Committee E.7 on Radiographic Testing. In the first paper exposure graphs for the radium radiography of steel are discussed. The relationship between gamma-ray exposure types of film were investigated by placing a number of pieces of film spaced along radii at different distances from the radium capsule and removing and developing them after a known period of time, thus obtaining a series of exposures of different intensities. With distances chosen to give densities ranging from about 0·5 to 3·0, a series of exposures were made for each type of film with no steel and with ¼, 1, 2, 3 or 4 in. of steel in front of each piece of film.

From the densities obtained on the exposed films, and from the exposure factors required to produce these densities a series of curves, one curve for each thickness of steel, was plotted for each type of film. From these curves the exposure factor required to obtain any specified density was found for each thickness of steel. When these exposure factors were plotted against the various thicknesses of steel an almost straight line was drawn through them. Similar curves were obtained for each density and the series of five curves obtained gave an exposure graph for a particular type of film. In the preparation of these graphs, types K, F and A, Blue Brand, No Screen and AGFA 874 Kodak films were used.

The slope of the density-exposure factor curve at any density is a measure of the contrast of the films at that density. Films divided themselves into two groups, in one of which (types K, BB and F) a constant slope was reached between densities 1 and 1·5 and in the other group (no-screen), A and 874 the slope appeared to increase up to density 3·0. Another measure of the contrast and of the sensitivity was the decrease in the density brought about by an increase in thickness of steel for some constant exposure factor. The latitude of the film is also an important characteristic since it determines for any given thickness, the maximum and minimum exposures which will result in a usable radiograph, and for any given exposure it determines the maximum and minimum thickness which can be seen adequately in the same radiograph. Wide latitude is associated with low contrasts, and again the films divided into two groups: Types K, BB and F, which had wide latitude, and types A and 847 and no-screen, which had much less latitude.

The use of radium for the radiography of steel and bronze has been limited to sections of 1 in. or more in thickness, due, in part, to unsatisfactory sensitivity at thickness of less than 1 in. with the screen type film usually recommended for radium radiography. To ascertain the penetrameter sensitivity for ½ in. steel experiments were carried out with the new high-contrast fine-grain films. Similar films to those used for the exposure graph tests were used in with du Pont 506 and AGFA 674 films added. The results obtained are given in the second paper of the series and show that, in general, there is a minimum density below which the penetrameter could not be seen. The thinner the penetrameter the higher was the maximum density required. The approximate minimum densities found for each penetrameter and for each film are given in the table below.

In the radium radiography of thin steel sections to insure the visibility of 2% penetrameters it was found that the minimum density should be about 1·5 to 1·6, and the visibility is better as the density increases. Exposure graphs are required, since the most suitable films used have small latitude and therefore the exposures must be accurately estimated in order to get the desired density. The exposure data showed that for ½ in. of steel an exposure factor of 130 to 150 was required for type A, 506, 674 and 847 films and an exposure of 400 to 450 was required for M film. Film-handling and developing technique should be of high quality, a small source size is a distinct advantage, since the edges of the defects will be sharper and can be more readily seen, and good viewing conditions make the difference between seeing the defects which the radiograph records and missing them. Radium radiography of thin steel also requires that a bright light source should be available, since high density is essential, that the film should be so shielded that there is no adjacent area brighter than the film itself.

In the third paper the use of film to measure the exposure to gamma rays as an aid in establishing and maintaining safe working conditions is discussed. A method of measuring the exposure received at any point, or by any person, over a period of time is required, and the essential basis of such a method is the establishment of

Penetrameter %	Type F	No-Screen	Type A	674	506	874	Type M
2	—	2·8	1·6	1·6	1·6	1·3	1·4
3	—	1·6	1·4	1·1	1·1	1·3	1·4
4	1·1	1·1	1·0	0·8	0·8	0·9	0·9
5	1·1	1·1	1·0	0·8	0·8	0·9	0·7

[1] *Amer. Soc. for Testing Materials Bulletin.* 1944, No. 127, March, pp. 25–32.

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a relationship between the amount of radiation received by a film and the blackening of the film thus produced. By experiment data can be obtained from which a blackening curve can be plotted, at density versus exposure factor, which can be used for any combination of radium, distance and time and from this curve any degree of film blackening can be interpreted in terms of exposure factor. Test films should be prepared from the same lot as those used in obtaining the blackening curves, and for high accuracy, conditions of exposure and development should be the same for both films, and variation in development of the films, must be guarded against. In the experiments carried out, a tolerance dosage of 0·1 röntgen per 7-hour day was used = an exposure of 4·93 per 7-hour day, or 29·6 per 6-day week, and the blackening corresponding to this exposure factor was obtained from the characteristic curve for any film.

Silver Brazing of Tools and Gauges

By F. L. Woodcock

TOOLS and gauges, like other items of equipment and supply for manufacturing purposes, have a limited life in that they wear out and suffer breakage. A large proportion of all broken or worn-out tools and gauges can be reclaimed and their life extended by simple and economical methods. They can be reconditioned and restored physically to their original appearance and usefulness, and tools can also be designed to provide for a more extended life in service through simple regrinding operations. By far the major part of tool reclamation work is the repair of broken tools and the rehabilitation of worn-out tools and the important question involved in such work is the method of repair in reconditioning. Various methods are available—brazing welding, hard chromium plating, metallising, etc.—and each have their relative advantages, although, in most instances the simplest, least expensive and most satisfactory method is brazing.

Among the outstanding brazing mediums in use are the low temperature silver brazing alloys which produce joints which are exceptionally high in strength. The advantages obtained from such alloys are that a very low working temperature or flow point can be obtained (635° C. with a silver-cadmium-zinc-copper alloy) which means short heating time and a minimum of distortion and reduction of hardness of the tool. This reduction seldom amounts to more than 1 to 3 points on the Rockwell C scale, which does not lower the effectiveness of the tool, thereby saving the need of re-hardening. At this low temperature the alloy is extremely free flowing and capillary action carries it into every part of a joint area. As it can be used with minimum joint clearances, the thinner the film the stronger the joint.

In brazing broken tools, two primary steps are involved, consisting of preparing the part for brazing, which includes cleaning the surfaces of the joints, fluxing, pre-placing the brazing alloy, and setting up the jig or holding mechanism as required, and applying heat by gas torch in a muffle furnace, dipping in a molten salt bath or by induction heating.

Proper fluxing is essential to a good brazing operation and the flux should melt at a temperature notably below the melting point of the brazing alloy. In technique there are three basic methods of brazing: (1) Feeding the silver brazing alloy by hand in the form of wire; (2) "Pre-placing" sheet or strip of the alloy between the parts to be brazed and (3) "Pre-tinning" the broken surfaces with silver alloy. For small tools or small joint areas, feeding the wire is satisfactory, as the parts can be fluxed and clamped in place, then wire or strip put on the top of the joint. Large tools call for "pre-placing" the brazing alloy or "pre-tinning" the broken surfaces, the object being to have the silver alloy reach every part of the joint area as quickly as possible without excessive heating. For pre-placed strip various gauges can be used, but 0·003 in. has been found best in most cases, being the thinnest practical gauge, as it readily confroms to the contour of the broken surfaces when the parts are clamped together.

Any standard type of heating may be used successfully for silver brazing, but the oxyacetylene torch has been found best because of its speedy action and flexibility. The best technique for this heating consists in setting the torch for a neutral to reducing flame, keeping the torch moving to avoid hot spots and to heat the work uniformly, bringing the joint and the surrounding metal to the proper temperature and applying the brazing alloy in the proper manner. Where the silver brazing alloy is pre-placed, the heating technique is similar, but the operation is simpler, as it is only necessary to keep the flame moving over the joint and the surrounding areas until the brazing alloy has melted completely. In pre-tinning the same procedures are also used for cleaning, fluxing and heating. Furnace heating (oil, gas or electric) is highly satisfactory for air-hardening types of steel or carbides, giving uniform heating and accurate temperature control. Immersion heating has the advantages of rapidity, good control, uniformity of heating and protection from atmospheric oxidation and is particularly useful for volume work. Induction heating offers several advantages, especially for parts of uniform shape and thickness, because of its rapidity, the automatic heat control and the localised heat close to the joint. Methods of preparation for all forms of heating—oxyacetylene torch, furnace, immersion and induction, are the same, namely—cleaning, fluxing and pre-tinning or pre-placing the alloy. In every case care must be exercised to keep the heating period as short as possible and to leave the tools undisturbed until they have cooled sufficiently for the brazing alloy to set.

From *Metals and Alloys*, 1944, vol. 20, No. 2 pp. 78–82.

Helium Used in Magnesium Production

AN improved method for the production of magnesium from its ores is the subject of a patent recently issued by and assigned royalty-free to the U.S. Government. Standard procedure for freeing magnesium from its oxides is to heat it with a carbonaceous material which takes up the oxygen and releases the magnesium in vapour form. To prevent the magnesium from re-oxidising, hydrogen or some carbon-containing gas is usually introduced during the cooling process. This, however, forms dangerously explosive mixtures. The patent substitutes the inert safety gas, helium, eliminating this difficulty. The agglomeration of the cooling magnesium into droplets is speeded by subjecting the vapour to intense but inaudible supersonic vibrations.

From *Chemical Industries*, August, 1944.